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THE DESIGN AND CONSTRUCTION OF THE ST. JOHNS BRIDGE AT PORTLAND, OREGON.

BY

D. B. STEINMAN, M. Am. Soc. C. E.

SYNOPSIS.

The St. Johns Bridge, spanning the Willamette River near its junction with the Columbia, involved 4,000 feet of bridge construction and 5,000 feet of approach construction. The main suspension span of 1,207 feet is the longest span of any type west of Detroit, and its clear height of 205 feet above navigable water sets a high record for officially required underclearance. It is the longest rope-strand suspension span in the world. The design was marked by unusually complete *scientific*, *economic* and *æsthetic* studies, and the execution of the work established an outstanding record of economy below the authorized appropriation.

Among the novel and distinctive features of the *design* were: the use of tall arched concrete viaduct piers reinforced with structural steel frames, including the highest reinforced concrete rigid-frame pier in the world (163 feet high); the first use of lofty arched main steel towers (400 feet high above M.L.W.) without conventional diagonal bracing; the checking of the computed deflections and stresses in the main towers of unusual design by precision laboratory tests on a scale elastic model; the substitution of pre-stressed rope strands for conventional parallel wire cable construction, resulting in the largest rope-strand cables thus far constructed; special laboratory and design studies to reduce the effects of lateral pressure on the rope strands in the main saddles; the first substitution of riveted silicon steel plates for the eyebars usually employed in the anchorage chains; the first use of reinforced concrete pedestal piles for the foundation of an anchorage; the first use of auxiliary rope strands incorporated in the cable backstays to anchor the tops of the rocker cable bents; the development of a novel rocker cut from H-beams for the expansion ends of truss spans; and the artistic studies of the entire design for harmony and for pleasing appearance from all angles.

(Note.—The Franklin Institute is not responsible for the statements and opinions advanced by contributors to the JOURNAL.)

Among the novel or unusual features of the *construction* were: the division of the work into seven simultaneous main contracts, with almost countless ramifications of subcontracts, creating special problems of scheduling, coördination, and adjustment; the first extensive use of Transit Mix concrete in the construction of a large bridge; the erection of the main towers by the use of timber falsework of record-breaking dimensions; the development of a tramway system for erecting rope-strand cables; the novel use of a cableway to aid in erecting the viaduct steel; and the erection of the stiffening trusses without the use of a traveler or derrick.

The bond issue voted for this bridge by Multnomah County was $4,250,000, based on estimates for a 3-lane structure. Through economic design and construction, the County has secured a 4-lane bridge of artistic distinction, at a total cost (including right-of-way, administration, engineering and all other costs) generously below the authorized appropriation, leaving about $300,000 unexpended.

LOCATION OF THE BRIDGE.

The St. Johns Bridge was built by Multnomah County, Oregon, to span the Willamette River between two sections of the City of Portland, the St. Johns district on the east bank and the Linnton district on the west bank. The location is about seven miles northwest of the business center of the city. It will afford a connection between the Upper Columbia River Highway east of Portland and the Lower Columbia River Highway from Portland to Astoria.

FIG. 1.

St. Johns Bridge, including approaches.

Five different locations were studied, four at different streets (Fessenden, Baltimore, Philadelphia and Pittsburg) near the center of St. Johns, and one (at Tyler Street) about a half-mile south. The total range in estimated cost for corre-

sponding designs at the five locations was found to be $970,000. The most economical location was found to be at Baltimore Street, but the adjoining location along the center line of Philadelphia Street (costing only $160,000 more) was adopted as preferable for city planning considerations.

The east approach of the bridge follows the center line of Philadelphia Street in St. Johns. The viaduct approach starts at the intersection of Syracuse Street, and ascends 1,511 feet on a 3½ per cent. grade to junction with the suspension bridge.

The west approach viaduct spans St. Helens Blvd. and runs abruptly into the steep rocky hillside on the west bank of the river. The elevation of the west abutment, on this hillside, is approximately 180 feet, necessitating two long approach roads, extending to the north and to the south, to come down to the grade of the existing highway. The construction of these approach roads, amounting to a mile of steep sidehill construction in rock cut and including some additional spans across a ravine, constituted one of the seven main contracts into which this project was divided.

PRINCIPAL DIMENSIONS.

The main span of the St. Johns Bridge clears the harbor lines with a length of 1,207 feet center to center of main piers, and is flanked by two suspended side spans each 430 feet 3 inches long. The cable sag is 120.7 feet, one-tenth of the span.

In order to meet navigation requirements established by the Port of Portland, the underclearance was made 205 feet at the center of the main span. This is believed to be the highest underclearance ever established officially as a navigation requirement for any bridge thus far built.

ÆSTHETIC DESIGN.

In the design of the St. Johns Bridge, the desire to secure a beautiful public structure was a governing consideration.

It was soon found that beauty could be secured without sacrifice of economy. Comparative designs and cost estimates showed that a suspension design, with its naturally graceful cable curves and its other features of superior æsthetic dis-

tinction, could be built for a cost $640,000 lower than that required for a cantilever bridge of equal capacity.

With this saving available, and utilizing only a part of it ($400,000), it was then decided to increase the width of the authorized bridge from three traffic lanes to four. The more generous width thus secured yielded, as an incidental advantage, a further enhancement of the appearance of the structure, including improved proportions of the high towers, tall piers, and long spans.

A design with balanced suspended side spans was developed, yielding the desired symmetry of cable curves at each tower.

The design of the lofty main towers was selected by the County Commissioners from 25 designs prepared and submitted by the engineers. The adopted design is an attempt to secure, in a steel tower, artistic and graceful lines expressing a harmonious combination of beauty and strength. The tower has vertical legs to support the direct load of the cables, in conjunction with batter legs for bracing and stability. With either vertical legs or batter legs alone, it is difficult to secure a fully satisfying effect; in the one case the tower tends to appear top-heavy; in the other case the tower assumes awkward angularity. The combination, with its obvious fitness of form to function, is the most satisfying to the eye.

In the design of the tower, it was decided to eliminate the stereotyped diagonal bracing. Instead, pointed arches, both above and below the roadway, constitute the dominant motif. The impressive effectiveness of the lofty Gothic arches in the tower portals of the Mount Hope Bridge prompted the adoption of this feature for the St. Johns Bridge. Each half of a pointed arch expresses a combination of bending and direct stress, and these are the governing stresses in such tower. It is a form readily produced in steel. The pointed arch appears to be inherently more appropriate to steel than it is to voussoir masonry which had to be used before steel became available. In the case of a suspension bridge, the Gothic arch appears to be particularly appropriate as a dominant motif, since its characteristic feature of curves meeting in a point is also the outstanding feature of the principal lines of the structure constituted by the cables.

The tower columns are worked out in cruciform section, for massiveness and relief. The outer face is treated with alternating plates and latticing, for interest and scale. The upper portal web is provided with conspicuous vertical stiffeners, to give visual as well as physical strength and to break up the wide surface with lights and shadows for contrast and relief. The tower is surmounted with appropriate spires, of exaggerated height to compensate for perspective shortening, and these carry the flashing lights required as aviation beacons.

The adopted design for the main piers was selected by the County Commissioners from six different designs prepared and submitted by the Engineers. With the aid of horizontal moulding lines, and with slight sculptural relief designed to harmonize with the lines and curves of the superimposed steel tower, there was secured an effect of richness and interest of form not found in concrete piers of stereotyped design. The extra cost, if any, is negligible; and the much greater cost of stone facing, which could hardly have produced more effective results, was avoided.

The architectural theme of the main towers, with pointed arches and buttresses, was continued in the design of the tall reinforced concrete piers of the viaduct approach, so as to produce an effective arcade of vaulted openings of ascending height. Each pier consists of two shafts of tapering cruciform section, with their inside faces converging at the top to form lofty pointed arches. With slight curve at the base and taper toward the top, the graceful lines of the buttressed shafts effectively express material and function. With lofty flowing lines of strength and grace, and with vaulted openings ascending to a height of 150 feet above the ground, a beautifully impressive arcade is produced.

At the junctions of the stiffening trusses with the main towers, false top chord members are omitted, leaving a triangular gap to frame the sidewalk bracket. The combination of the interrupted top chord with the added feature of curved brackets produces a most pleasing solution of the æsthetic problem of stiffening truss support.

For the approach viaduct spans, a design was developed with parallel chord trusses of subdivided panels, and with duplication of motif and panel dimensions, so as to secure the

æsthetic elements of continuity, repetition, and rhythm. Each span, in lines and dimensions, forms an integral part of a harmonious ensemble. There is no incongruous angularity of outlines or haphazard arrangement of web members as would occur in a strictly utilitarian layout of truss spans without regard to æsthetic considerations. Instead of angular confusion, there is harmony of line and parallel, rhythmic repetition of an artistic pattern. The duplication of spans, panels, and details, adopted for the sake of appearance, also has its economic value in reduced fabrication and erection costs.

Special consideration was also given to the final color of the steelwork. Departing from the cold somber grays and blacks conventionally used in bridge paints, a warmer and more pleasing color was adopted in a light, restful tint of green that harmonizes with the setting while standing out against the dark green of the landscape. Atmospheric depth adds a bluish tint to the light green, producing a pleasing effect of a framed design of different hue when the more distant tower is seen through the portals of the nearer tower.

The copper-sheathed spires, flashing in the sunlight, are left unpainted so that they will weather to a verde-green that will match the tint of the painted steelwork.

Special designs for the ornamental balustrades, the lighting standards and other details were developed to harmonize with the main towers. Details of the abutment pylons and parapets, the viaduct piers, the massive main piers and the anchorages were modeled to the graceful curves and contrasting reliefs of the governing style. A special attempt was made to develop each material in a manner appropriate to its essential characteristics.

BORINGS.

Preliminary wash borings were made along the lines of five different locations as a basis for the preliminary designs and comparative estimates. After the final site was selected, final confirmatory core borings were made at the locations of the piers and anchorages.

On the east bank the borings revealed only clay and sand, which necessitated a substructure design with spread footings, and with pile foundations under a number of piers.

On the west bank the borings showed rock at Elevation − 11 to − 23 for the west main pier, and rock under 4 to 8 feet of clay for the viaduct piers and the anchorage.

DESIGN OF VIADUCT PIERS.

The viaduct piers are of reinforced concrete and were designed with special consideration to effective appearance.

The twin shafts of these piers rise from heavily reinforced concrete footings and are connected at the top with pointed arches. The successive piers ascend in height, reaching Elevation + 160 at Pier No. 10. It is believed that this pier, 163 ft. from top to bottom and containing 3,950 cubic yards of concrete and 150 tons of reinforcing steel, is the largest reinforced-concrete rigid-frame pier yet constructed.

The piers are reinforced with structural steel frames supplemented with rod reinforcement. The structural steel frames are set-in 4 inches from the face of the concrete, and are rigidly braced to form a rigid support for the outside forms. They constituted the greatest factor in attaining perfection of shape and line of the tall, tapering pier shafts. In addition to this function of facilitating construction, the structural steel frames served as part of the necessary reinforcing steel for the pier figured as a rigid frame to withstand vertical, longitudinal and transverse loads. The main shaft angles of these steel frames are 6 x 6 x 1/2 in. and 4 x 4 x 3/8 in. angles. At vertical intervals of 3 ft., the main angles were braced in a horizontal plane by 3/4-inch diameter rods with turnbuckles for adjustment.

The design of the structural steel frames included special provision for temporary steel trusses to support the centering for the arches near the pier tops. These trusses, spanning the opening between the shafts, were moved from pier to pier as the work progressed.

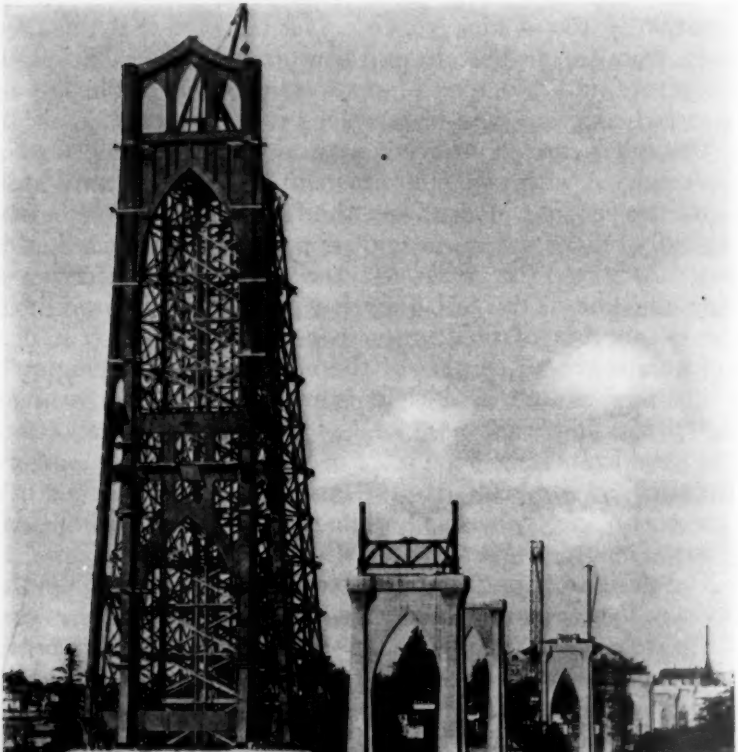
The balance of the required reinforcement for the piers, to supplement the structural steel frames, was made up of $1\frac{1}{4}$-in. reinforcing rods.

DESIGN OF MAIN PIERS.

The two main piers were designed of reinforced concrete, with horizontal moulding lines and moulded relief to give interest and contrast to the surface appearance.

The design of the tower with batter legs introduced excess length in the pier dimensions. In order to save concrete and reduce weight on the foundation, 43 wood-stave pipes, 75-in. diameter, were placed vertically in the body of each pier so as to leave hollow cylindrical shafts in the concrete. They were located where no direct load came on the pier, and ample reinforcement surrounded each shaft.

FIG. 2.



East main pier during tower erection.

The east main pier, No. 11, has its foundation at Elevation − 50 (referred to mean low water) on 1,068 wood piles, 20 ft. to 47 ft. long, driven under water into hard sand. This pier contains approximately 17,000 cubic yards of concrete and 110 tons of reinforcing steel.

The west main pier, No. 12, is founded on rock at Elevation − 25. It contains over 9,000 cubic yards of concrete and 60 tons of steel reinforcement.

DESIGN OF ANCHORAGES.

The east anchorage is 115 ft. long by 91 ft. wide, and extends from Elevation + 12 to + 82. It contains 12,500 cubic yards of concrete. In addition it is provided with hollow chambers filled with sand to provide additional weight while saving concrete. The total weight of the anchorage is 29,000 tons, to resist the cable pull of 8,500 tons. The anchorage also has hollow chambers provided to permit inspection of the ends of the cables and anchor chains.

The anchorage has a stepped foundation on a spread footing which is supported on 516 reinforced concrete MacArthur pedestal piles. The piles are spaced 4′–3″ on centers, and average 30 ft. in length. Their function is to provide additional horizontal and vertical resistance. In order to increase the horizontal resistance, 192 of the piles are battered on a 1 : 4 slope.

The west anchorage is provided in two sloping tunnels 85 ft. deep in the dense basaltic rock of the hillside. The construction of these tunnels involved 2,000 cubic yards of solid rock excavation. At their lower ends, the tunnels are enlarged to form wedge shaped chambers; these receive the anchor girders which are embedded in the concrete filling the tunnels.

For the anchor chains, silicon steel plates with reinforcing pin plates were substituted for the usual eyebar construction. These silicon steel plates with the riveted pin plates were subjected to full-size tests similar to those required for eyebars. They were proportioned for a working stress of 24,000 lbs. per square inch in direct tension.

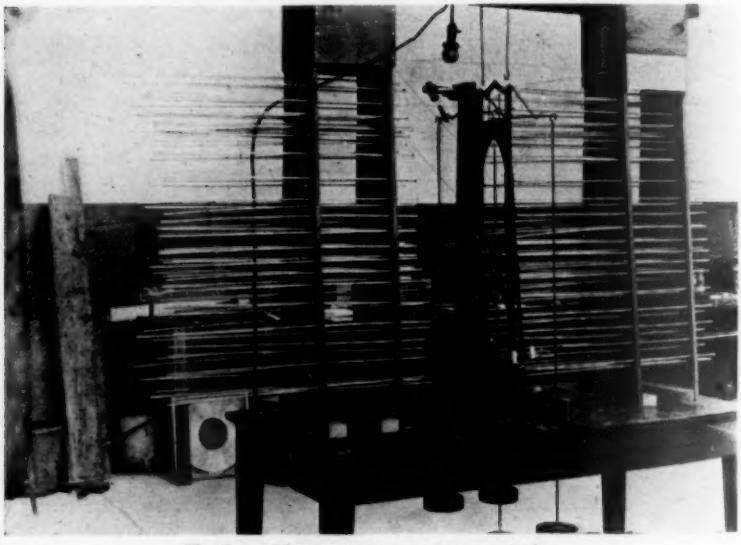
The heel of the east anchorage supports viaduct pier No. 8. The west anchorage tunnels are surmounted by an

exterior structure supporting viaduct piers Nos. 14 and 15. In both anchorages, the concrete above ground is treated with mouldings and relief to harmonize with the architectural design of the main piers.

DESIGN OF MAIN TOWERS.

The main towers are of medium carbon steel, of the semi-flexible type, fixed at the base. Each tower consists of two main vertical columns, 52 ft. center to center (corresponding to the spacing of the cables), supplemented by outside batter legs spread to 88 ft. $7\frac{5}{8}$ in. center to center at the base.

FIG. 3.



Elastic model tests to check main tower design.

The tower legs are of tapering cruciform section, with box divisions forming a cellular construction. The main column section tapers from a width of 18 ft. at the base to 7 ft. 4 in. under the saddles, with a constant breadth of 4 ft. 1 in. The total height of the towers, including the finials, is 400 ft. above the mean low water stage of the Willamette River.

Following the mathematical analysis of the deflections and stresses in the main towers, check tests were made on an

elastic model, over 4 ft. high, built up of sheets of celluloid to represent the variations of cross-section and moments of inertia. Scale forces were applied to represent the simultaneous action of maximum vertical and transverse loads on the tower. Precision strain gauges were used to read the stresses and filar microscopes to read the deflections. This work was done by the writer's assistants, with the coöperation of Professor George E. Beggs, in the engineering laboratory of Princeton University.

The model test results were distinctly reassuring, being in all cases lower than the computed stresses and strains. The indicated maximum transverse deflection of the tower top, referred to the scale of the actual structure, was $2\frac{3}{8}$ in. from 30-lb. wind load combined with the effect of the resultant eccentricity of the maximum vertical reactions from cable and truss loads. The maximum indicated fiber stress, after adding the computed stress from unbalanced cable pull, was only 14,000 lbs. per square inch. The model tests showed that the tower was generously proportioned for any combination of stresses to which it might be subjected.

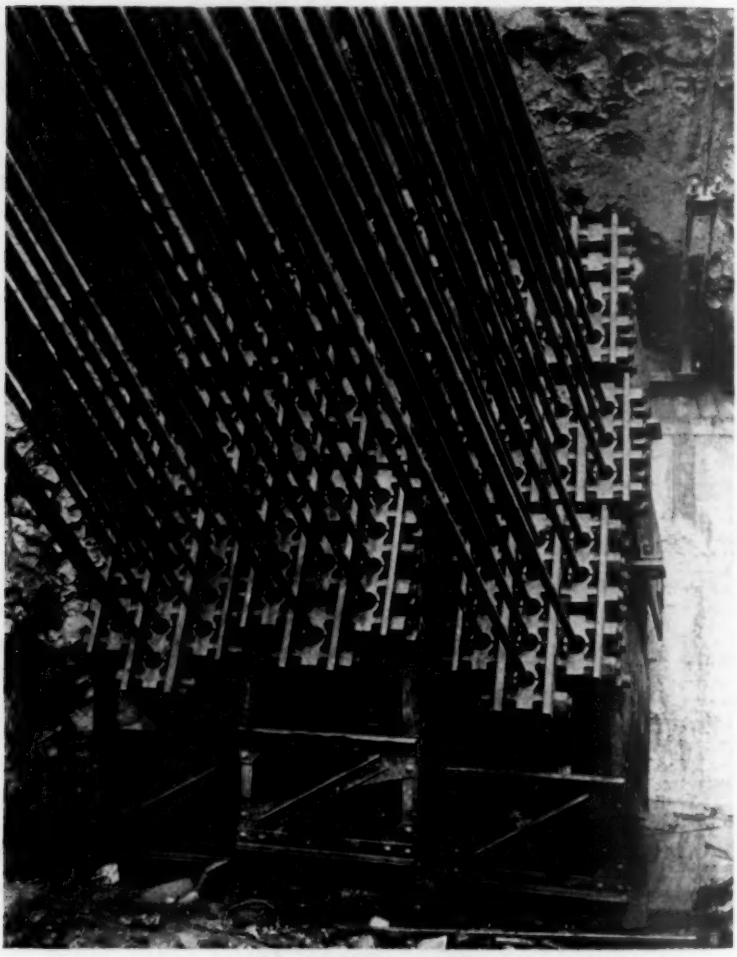
Atop each main leg of each tower is mounted a 50-ft. spire. This is of structural steel covered with copper sheathing, and is secured to the ribs of the cable saddle. Each spire supports an airport code lantern containing two 200-watt P.S.30 lamps and equipped with motor flasher. These aviation lights were provided to meet the requirements of the Bureau of Lighthouses of the U. S. Department of Commerce.

TWISTED STRAND CABLES.

Following the successful application in 1929 of twisted strands for the cables of the 950-ft. span Grand'Mere Bridge in Quebec, the specifications for the St. Johns Bridge invited bids on twisted-strand construction as an alternative to the parallel wire cable design. The two alternative bids of the John A. Roebling's Sons Company were lower than any other bids received for the cables and showed a saving of $42,000 by adopting the twisted-strand design. Moreover, the proposal announced an expected saving of two months in the time of completion of the bridge, this saving in time being made possible by dispensing with the construction of foot-

bridges and by shortening the time required for cable stringing.

FIG. 4.



Strand anchorage assembly.

In the parallel-wire design, the cable diameter was specified as $12\frac{3}{4}$ in., but the use of twisted strand construction increased this to $16\frac{3}{4}$ in. An incidental advantage accruing from the increase in cable size was an improved appearance of the

bridge as a whole, due to the more substantial aspect of the principal carrying member.

The parallel wire design provided for each cable to consist of 19 strands of 184 No. 6 galvanized wires each, yielding a sectional area of 105.47 square inches per cable. The specified physical properties were 170,000 lbs. yield point, 225,000 lbs. ultimate strength and 27,000,000 lbs. modulus of elasticity.

The specification required the twisted-strand design to match the parallel wire design in guaranteed total ultimate strength, total yield point and total resistance to elongation. These requirements were more than met by the adopted design. In each cable, as adopted, there were 91 twisted strands of $1\frac{1}{2}$ in. diameter, yielding a metallic sectional area of 121.64 square inches. The ultimate strength per strand was 135 tons guaranteed and 150 tons actual. The guaranteed yield point was 75 per cent. of the ultimate strength. The modulus of elasticity was 22,000,000 lbs. guaranteed and 25,000,000 actual.

The first use of twisted strands for cable construction appears to have been in the suspension bridge of 400-ft. main span at Massena Center, New York, designed and built by H. D. Robinson in 1910. The bidding plans for the Florianopolis Bridge in Brazil, by Robinson & Steinman, in 1922, included an alternative cable design with twisted strands. The development of pre-stressing to raise the value of E rendered possible the economical application of twisted strands for the Grand'Mere Bridge of 950-ft. main span, designed by Robinson & Steinman in 1928.

The new suspension bridge over the Rhine between Cologne and Mühlheim, completed 1929, has cables of twisted wire *ropes* (patent locked wire type); its main span of 1,033 ft. is the longest on the European continent. The St. Johns Bridge extends the range of demonstrated economy of non-parallel wire cable construction to a span length of 1,207 feet.

For shorter spans, twisted strands offer more obvious economy. Twisted strand cable construction was adopted by Robinson & Steinman for the official design of the Waldo-Hancock Bridge of 800-ft. main span at Bucksport, Maine, (completed 1931), also for the official designs by the same

firm for the two suspension bridges at Shelter Island, N. Y., of 700 and 1,100 ft. main span, respectively, to be constructed 1932–1934.

The St. Johns Bridge cables are the largest rope-strand cables thus far constructed, and the St. Johns Bridge is the longest suspension span thus far built with cables of other than parallel-wire construction.

MAIN CABLE SADDLES.

One of the problems in twisted-strand cable construction is the limitation of maximum lateral pressure on the strands, as for instance in the cable saddles where the bottom strands are subjected to concentrated vertical pressure from the superimposed strands. The unprecedented magnitude of this construction in the St. Johns Bridge made it necessary to give special study to this problem of excessive lateral pressure on the strands.

To aid in a solution of the problem, tests were made at the Trenton plant of the John A. Roebling's Sons Company to determine the effect of transverse pressure on the physical properties of the strands under tension. Previously published tests had shown that cable wires are unaffected in strength and yield point by pressures of 3,300 lbs. per linear inch of wire. The tests performed for the St. Johns Bridge showed that even higher pressures did not affect the physical properties of twisted strands, although they did produce visible deformation of section of the wires in the outer layers. It was decided to limit the maximum pressures to 3,300 lbs. per linear inch. This was accomplished by rearranging the strands in the saddle, so as to have eight strands in the bottom layer instead of six and so as to reduce the number of horizontal layers from eleven to ten. In addition, the radius of the saddle curve was increased. As a further precaution, the strands of adjacent horizontal layers were specified to have opposite lay, so as to secure "valley" contact rather than "crossing" contact between the contiguous wires.

CABLE BENTS.

The cable bents are steel rocker bents, mounted on the tops of Piers 10 and 13. Their function is to support the

cables at the points where their suspension function terminates and they turn down in steeper lines toward the respective anchorages. A very substantial economy is effected by this device, permitting shorter suspension spans, reduction in height and size of anchorages, and more favorable location of anchorages. In the case of the St. Johns Bridge, a saving of $1,000,000 may be credited to this feature of the design.

The cable bents were provided with wing plates at the base to hold them in position during erection; these plates were burned off after the cables were in place.

The connection between the cable bent columns and the side span stiffening trusses was made by means of 6-in. pins in lubricated bronze bushings. These take the vertical reactions of the ends of the side spans.

A transverse truss in the cable bent supports the rocker bearings for the 180-ft. approach span and the center-line sliding bearing for the lateral truss of the suspended side span.

The cable bents rest on line bearings on cast steel pedestals, to permit rocking. This accommodates the thermal and elastic variations in length in the backstay cables between anchorage and cable bent.

CABLE BENT SADDLES.

The cable bent saddles in the St. Johns Bridge represent a departure from previous design in that anchorage for each saddle is provided by means of auxiliary rope strands instead of by friction clamping of the cable strands in the saddle.

Where friction is the sole means for taking up the difference in cable tension on the two sides of the cable bent saddle, the necessary clamping of the cable in the saddle introduces additional lateral pressure on the cable strands. For the St. Johns Bridge, it was decided to substitute a more positive anchorage between cable and cable bent saddle, and this was provided by incorporating five additional twisted strands in the cable backstay and anchoring these auxiliary strands to the saddle. The five extra $1\frac{1}{2}$-in. strands are pin-connected to the saddle casting at points underneath the main cable bearing and, after leaving the saddle, are incorporated with the other 91 strands to make a 96-strand section for the backstay cable. A tapered metal hood covers the transition section of the cable.

The cable bent saddles, like the main tower saddles, are hexagonal in interior profile, and the interior faces are cut with grooves to fit the cable strands. An upper casting of similar interior profile constitutes the saddle cap, and this is bolted to the main casting to furnish a moderate clamping action on the cable.

DESIGN OF STIFFENING TRUSSES.

The stiffening trusses are spaced 52 ft. center to center, to provide for a 40-ft. roadway and two 5-ft. sidewalks. The truss depth was made 18 ft., or 1/67th of the main span. The panel length is 19 ft. 3 in.

The stress analysis was made by the "Deflection Theory," using the formulas and charts in the writer's treatise on "Suspension Bridges."

The truss chords are of silicon steel, with a 45,000-lb. yield point and an 80,000 to 95,000-lb. ultimate strength. They are proportioned for a working stress of 32,000 lbs. per square inch, for extreme combination of live load, wind load, and temperatures. Only two different sections were required for the upper chord, namely two 15-inch channels of 35 and 40 lbs. respectively, the heavier section being required only from the 1/6th to the 5/12th point of the main span. The lower chord sections also are two 15-in. channels of 35, 40, 45 and 50 lb. weights respectively.

The maximum working stresses for the medium carbon steel members are 26,000 lbs. for the stiffening truss diagonals, and 18,000 lbs. for the hangers, floor system, and bracing.

The truss splices were laid out for fabrication and erection of the trusses in two-panel units, 38½ ft. long. Expansion movement for the main and side spans is provided by supporting the spans on rocker posts at the main towers, and these rocker posts are covered by the end brackets extending under two panels each side of each tower. The connections at the top and bottom of the rocker posts consist of 6-in. pins in bronze bushings, provided with grease cup lubrication.

DESIGN OF VIADUCT SPANS.

The layout of the approach viaducts was planned for maximum duplication of span and panel lengths, together

with special consideration to æsthetic requirements. It provides three 180-ft. spans and four 144-ft. spans, both with truss depths of 18 ft., and three 108-ft. spans with truss depth of 9 ft. All panel lengths are 9 ft. A Warren trussing is used, subdivided in the deeper trusses, so that an inverted King-post truss with 45° diagonals becomes a repeated pattern. These viaduct trusses are deck type, 30 ft. center to center, the roadway and sidewalks being cantilevered out to obtain the total required width of 50 ft.

Each viaduct span has a fixed pin-connection at one end and a rocker expansion bearing at the other. The rocker bearing is of novel construction, devised by Robinson & Steinman. It consists of a section of H-beam, with the flanges planed to form curved bearing surfaces and provided with vertical stiffeners between the flanges. The American Bridge Company contributed the feature of welding the stiffeners instead of riveting them. This rocker design proved simple, economical and effective.

DESIGN OF ROADWAY SLAB.

The roadway slab on the bridge and viaduct spans is a 7-in. reinforced concrete slab, 40 ft. wide between curbs. It is divided into four 10-ft. traffic lanes by means of Erickson metallic disc markers, 6 in. diameter, set into the concrete at 6-ft. spacing. The curbs are 10 inches high.

The sidewalks are 4-in. reinforced concrete slabs, 5 ft. wide.

CONCRETE SPECIFICATIONS.

The specifications for the concrete for the St. Johns Bridge are believed to represent some departures from previous specification practice.

Three classes of concrete were specified, 1 : 6 concrete (for substructure), 1 : 5½ concrete (for roadway slab on structure), and 1 : 5 concrete (for roadway slab on west approach road). The 1 : 5 concrete was also adopted for the viaduct piers above the ground line. These classes of concrete were defined as follows:

1 : 6 concrete is concrete having not less than 5.64 bags of cement per cubic yard of concrete, not more than 6½ gallons of water per bag of cement, and a 28-day strength not less than 2,800 lbs. per square inch.

1 : $5\frac{1}{2}$ concrete is concrete having not less than 6.16 bags of cement per cubic yard of concrete, not more than 6 gallons of water per bag of cement, and a 28-day strength not less than 3,000 lbs. per square inch.

1 : 5 concrete is concrete having not less than 6.77 bags of cement per cubic yard, not more than $5\frac{1}{2}$ gallons of water per bag of cement, and a 28-day strength not less than 3,200 lbs. per square inch.

For each class of concrete, only three limiting conditions are prescribed. In other characteristics, such as proportions or grading of aggregates, the contractor is given generous leeway. He may also, at his option, increase the cement content or reduce the water in order to secure the prescribed strength. He will naturally prefer to meet the strength requirement by correcting any defect in the quality, grading or proportions of his aggregates.

Under these specifications, concrete of the desired quality and strength was easily secured.

CONTRACT COSTS.

The work was divided into seven main contracts, which were awarded in August and September, 1929, to the respective lowest bidders as follows:

A. Substructure:	
Gilpin Construction Company, Portland	$1,026,897.00
B. Fabrication and Erection of Bridge Steel:	
Wallace Bridge & Structural Steel Co., Seattle	986,445.80
C. Furnishing and Erection of Cables:	
John A. Roebling's Sons Co., Trenton, N. J.	472,200.00
D. West Approach:	
La Pointe Construction Co., Portland	267,603.40
E. Fabrication and Erection of Viaduct Steel:	
U. S. Steel Products Co., San Francisco	290,000.00
F. Concrete Deck:	
Lindstrom & Feigenson, Portland	146,060.00
G. Electrical Work:	
National Electric Company, Portland	33,000.00
Total Contract Cost	$3,222,206.20

This total amount bid on the seven contracts was $572,000 below the estimate of the engineers. The authorized bond issue for the bridge was $4,250,000. The final total cost,

including right-of-way, engineering, contingencies, and administration was approximately $3,900,000, so that a generous portion of the authorized appropriation remained unexpended.

The work involved about 120,000 cubic yards of excavation, of which 60,000 was in rock; 70,000 cubic yards of concrete; and over 9,000 tons of steel, of which 1,400 tons were in the cables.

TRANSIT MIX CONCRETE.

The St. Johns Bridge is believed to represent the first extensive application of Transit Mix concrete to bridge construction. Out of a total of 70,000 cubic yards of concrete in the bridge, 40,000 cubic yards were Transit Mix. Guaranteed to meet the specification requirements, it was delivered at the job at a price as low as $6.00 per cubic yard.

The sand, gravel and bulk cement were proportioned by means of a Howe platform scale of double beam and Weightograph type. The water was measured separately in a specially constructed tank calibrated to insure accuracy within 1/4 gallon in 100 gallons.

The dry batch of cement, sand and gravel was discharged into the drum of a Transit Mix truck, of 3 cubic yards capacity. The measured amount of water was discharged into a separate saddle-type water tank located above the mixing drum on the truck.

Before any water was admitted, the drum was turned 45 revolutions with the dry materials to insure thorough mixing of the batch. During transit five minutes or more before arriving at the job, the water was admitted to the dry batch and the drum was started rotating. The batch thus received a minimum of 60 revolutions at 12 R.P.M.

The Transit Mix concrete showed very favorable characteristics in ease of control, uniformity of product, adaptability to any pouring condition, and low cost. It easily met the specified strength requirements.

CONSTRUCTION OF MAIN PIERS.

The construction of the main piers was sublet to the Pacific Bridge Company of Portland.

Instead of excavating for Pier 11 through a cofferdam, the

subcontractors elected to dredge the bed of the river to the required depth, sloping off the sides of the excavation as required for stability. The advantages were greater ease of excavation, the utilization of the subcontractors' dredging equipment, and the more favorable conditions for the use of their pile driver.

The piles were driven through the sand to refusal and varied in length between 20 ft. and 47 ft. They were cut off under water, at Elevation − 50, by a circular cut-off saw mounted on a 2 in. 80 ft. vertical shaft operated by a 100 H.P. motor.

Then the timber crib, 80 ft. by 152 ft., was floated into position over the piles, ready to receive the seal concrete. Pouring of the seal, by tremie, was started January 14, 1930 and was completed February 8th after 7,000 cubic yards of tremie concrete had been poured to reach Elevation − 30. The 20-ft. depth of tremie concrete was then allowed two or three weeks to set. In view of the cold weather in which the work was done, the setting of the tremie concrete was carefully verified. Concrete test cylinders were suspended under water on top of the seal; when these tested to the required strength (March 3), the cofferdam was pumped out. Concreting, in the dry, was resumed on March 6, and the last pour for Pier 11 was made on March 21.

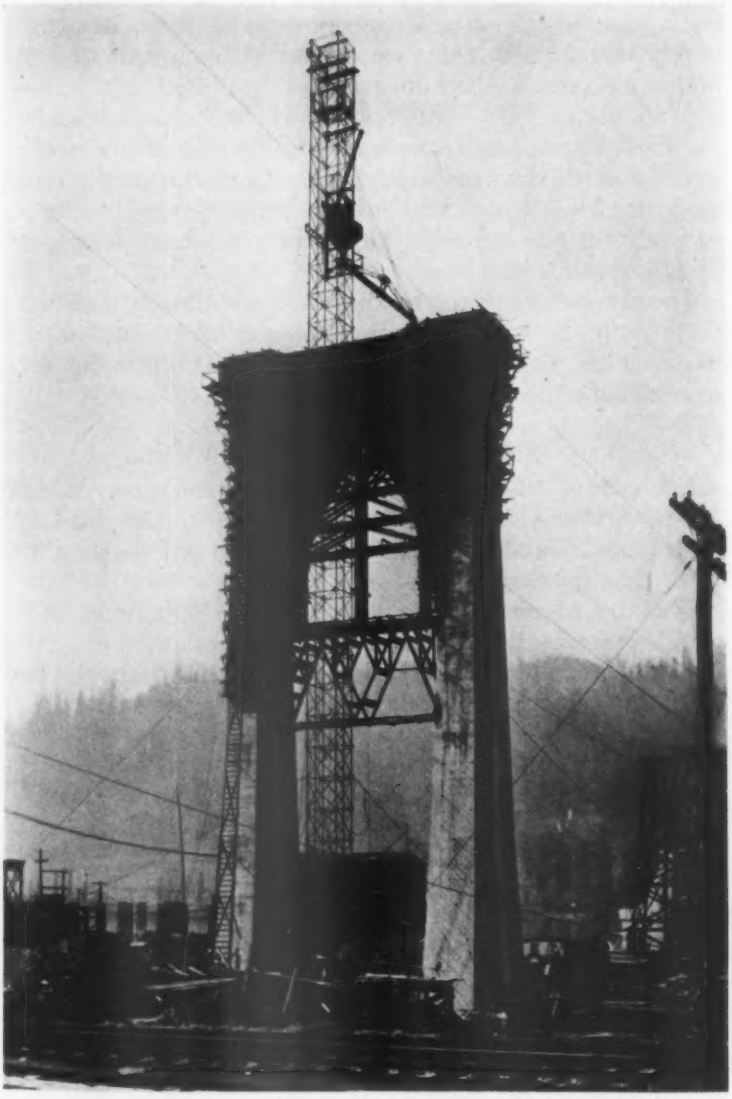
For the west main pier, No. 12, the crib cofferdam was set on the rock foundation excavated to Elevation − 25. The tremie seal was poured to Elevation − 13, or a concrete depth of 12 ft. The seal was completed February 20, 1930, the cofferdam was pumped out March 12, and the dry concreting was done from March 19 to April 8.

For pouring the seals, four tremies were used, each a 10-in. pipe 80 ft. long. The cofferdam was divided into four compartments, to localize the tremie pour.

CONSTRUCTION OF VIADUCT PIERS.

The viaduct piers were constructed by the Gilpin Construction Company of Portland. The contractor realized the significance of the viaduct piers in the architectural scheme and the consequent importance of trueness of outline and evenness of surface finish.

FIG. 5.



Viaduct pier construction.

The 600 wood piles under Piers 9 and 10 were driven on 3-ft. centers to sustain a safe load of 30 tons per pile.

The structural steel reinforcing frames were fabricated for erection in 20-ft. vertical sections. Delivered to the site entirely dismantled, they were erected by means of a light wooden gin pole. All connections were bolted.

After the pier base was poured, the structural steel frame was erected 20 ft. high, the additional rod reinforcement was placed, the wood forms were erected, and the section of pier was poured. Then, following the same procedure, another 20-ft. section was added. All of the piers were thus poured in 20-ft. vertical lifts.

The concrete surface of the piers was neatly finished by grinding off the form marks, rubbing cement wash into the surface with a carborundum stone, and removing excess material with the edge of a trowel.

CONSTRUCTION OF THE ANCHORAGES.

The pile foundation for the east anchorage was sublet to the MacArthur Concrete Pile Corporation. The piles are of the standard MacArthur Compressed Concrete pedestal type, except that reinforcing was used.

The 192 batter piles were driven by sloping the leads of the pile hammer. Despite unfavorable weather conditions, with temperature below freezing for half the time, the entire foundation of 516 piles was completed in 7 weeks.

Transit Mix concrete, amounting to 14,300 cubic yards, was used for both anchorages.

FABRICATION OF MAIN TOWERS.

For fabrication and erection, the tower legs, of cellular construction, were divided into 9 vertical sections. The aggregate height is 284.5 ft. from the milled face bearing on the base plates resting on the pier to the milled face supporting the plates under the cable saddles. The sections are stiffened by means of horizontal diaphragms spaced about 10 ft. along the height.

The towers were fabricated by the Wallace Bridge & Structural Steel Company at their Seattle shop. The entire tower was assembled and checked in the yard of the plant, to insure accuracy of fit and dimensions.

The design specified the milling of all tower sections to bear. The splice material and rivets (1 in. diameter) were proportioned for only 50 per cent. of the developed strength of the member. All connection holes were subpunched, and reamed to size with the parts assembled.

FALSEWORK FOR TOWER ERECTION.

A striking departure from the more usual method of tower erection with vertical creeper traveler was the adoption of massive timber falsework for the erection of the main towers of the St. Johns Bridge. The subcontractor, J. H. Pomeroy Company, Portland, elected this method in order to utilize the falsework timber salvaged after erecting the cantilever bridge at Longview, Washington.

On the shore side of each main pier, a timber falsework tower was constructed, extending to a height of 300 ft. above mean low water. Each falsework tower rested on a foundation of 56 timber piles, 100 ft. long at the east pier and 50 ft. long at the west pier. There were 252,000 ft. B.M. of timber in each tower, exclusive of the piling. The falsework was erected by means of a guy derrick operated as a creeper traveler inside of the frame. The main posts were 12″ x 14″ timbers, the girts were 8″ x 10″, and the diagonals were 4″ x 12″. All connections were bolted and spiked, and steel straps were used for splicing the vertical posts.

On top of each falsework tower was mounted a stiff-leg derrick with a boom consisting of a stick of Douglas fir, 28 in. diameter and 80 ft. long. This boom controlled the entire erection of the steel tower for its full height, without any shifting of the derrick. The back legs of the derrick were anchored down by two sand-box counter-weights, of 36 tons each.

ERECTION OF MAIN TOWERS.

Tower 11 was erected and riveted in 11 weeks; Tower 12 was erected and riveted in 9 weeks.

The bottom section of each tower leg was carefully set on 28 steel wedges resting on steel plates embedded in the pier concrete. When the steel reached the peak of the first arch, the legs were carefully plumbed both ways and the bases were grouted in.

Erection of the towers was easy and free, with ample drift available at all elevations. The heaviest piece lifted (part of the bottom section) weighed 34 tons. The greatest tonnage erected per day was 155 tons.

PRE-STRESSING OF CABLE STRANDS.

At the Trenton plant of John A. Roebling's Sons Company, each of the 182 rope-strands for the St. Johns Bridge cables was prestressed to a total tension of 150,000 lbs. (one-half of the ultimate strength) and held at this tension for ½-hour. The tension was then reduced to 70,000 lbs., corresponding to the average full dead load stress per strand in the completed structure. At this tension of 70,000 lbs., the strand was carefully measured to calculated length, which varies somewhat for the different strands with their positions in the cables. Correction for temperature was included in this measurement. The strand was then cut and socketed, reeled on a wooden reel, and shipped by steamer to the site. The weight of each strand, not including the weight of the reel, was nearly 6½ tons.

Tests made on samples of the rope-strands after prestressing gave uniform results for the modulus of elasticity. On the basis of these tests, a value of 25,000,000 lbs. per sq. in. was adopted for computations involving elastic stretch of the cable.

ERECTION OF CABLES.

The adoption of twisted strand construction made it possible to dispense with the footbridges ordinarily employed for stringing parallel wire cables. For the Grand'Mere Bridge in Quebec (1929), the rope strands were strung across the St. Maurice River on the ice and then individually lifted to position in the saddles. For the St. Johns Bridge, the cable contractor (John A. Roebling's Sons Company) elected to construct the cables by attaching the end of each strand to an overhead tramway line and "telegraphing" the strand across the river.

The plant layout for this method of cable construction consisted of an upper 1-in. diameter tramway line, a lower 3/4-in. diameter tramway line or "hauling rope," and, beneath these, two 1-in. diameter track rope strands per cable.

Each tramway line was an endless traveling rope serving both cables and passing through tightening frames on the east anchorage. The lower track rope strands were stationary,

FIG. 6.

Cable erection.

and were used to support and guide steel cages stationed at the quarter points of the main span and the mid-points of the side spans.

Along the upper tramway rope, at intervals of about 100 ft., were suspended steel U-shaped carriers. The lower tramway rope was used as a hauling rope for the strand which was to be pulled through the carriers suspended from the upper tramway rope.

The motive power for operating the tramway lines was located on the west anchorage. The $6\frac{1}{2}$-ton strand reels were mounted on reel stands on the east anchorage.

The socket at the end of a strand was attached to the lower tramway rope which proceeded to pull the strand through the suspended carrier guides, over the cable bents and main towers, to the anchorage on the west side of the river. There the socket was detached from the hauling rope and slipped into place between castings provided therefore in the strand anchorage assembly.

One strand was pulled across at a time, alternately for each cable. The time required was about $\frac{1}{2}$ hour per trip, to string a strand more than a half-mile long.

At first the strands tended to twist around the hauling rope. A new attachment was devised, with a swivel connection for the strand socket; this afforded the strand freedom to twist without wrapping itself around the hauling rope, and proved wholly effective.

The working cages mounted on the track rope strands were used for inspection and adjustment. Each cage could be clamped to the upper tramway rope and thereby moved to any position along the track ropes. It was found preferable, however, to leave the cages stationary and to have the men go out to their stations in the cages by means of boatswain chairs sliding along the track ropes.

Following the erection of each layer of strands, they were adjusted to their correct sags in each span with the aid of transit and level. No difficulty was encountered in the adjustment of the strands; this work was done early in the morning or after sundown to minimize temperature variations.

The rope-strands were erected approximately five feet short in length and eleven feet high in the main span to allow for elastic stretch in the cable due to the application of the dead load of the bridge. To overcome the tendency of

the free cable to slip through the saddles toward the anchorages, it was found, by calculation, necessary to tip the cable bents back 12 in. and 8 in. and to pull the towers back 22 in. and 18 in. The larger figures are for the east side of the bridge where the longer backstay is located. During cable erection, the east backstay was temporarily supported at the pier between the cable bent and anchorage in order to eliminate the sag at this point and thereby reduce the amount by which the east main tower had to be pulled back. The moment caused by bending the towers back gave rise to calculated tension in the pier concrete; but this effect was counteracted by temporarily weighting each pier with 250 tons of rails on the river side where the tension was indicated.

After all the strands were adjusted, the cast steel cable bands, grooved to receive the suspenders, were clamped around the hexagonal cable. The positions for the cable bands were carefully located, by measurement along the cables, at points spaced 38 ft. 6 in. apart horizontally for the completely loaded cable.

The cable bands are split on a vertical axis and the two halves are fastened together with high tension bolts placed horizontally on the top and under sides of the bands. In order to use the bolt tension most efficiently in producing friction between the cable bands and the rope-strands, zinc wedge blocks are placed on the top and under sides of the cables for the length of the cable bands. Due to this construction feature, the cable bands, when tightened, exert pressure on all sides of the cable.

WRAPPING OF CABLES.

The 91 twisted strands form a hexagonal cable. This is filled out to a cylindrical section with segmental strips before the outside wrapping is applied.

In the St. Johns Bridge, the hexagonal cable had a major diameter of eleven $1\frac{1}{2}$-in. galvanized rope strands, or $16\frac{1}{2}$ in. before wrapping. This was given two coats of paint and then the segmental fillers were applied. These consisted of Port Orford cedar, cut into segmental strips 6 ft. long and treated by immersion for 20 minutes in linseed oil at 200° F. When practically all of the dead load was on the suspended structure,

the cables rounded out with the treated cedar fillers were given their outside wrapping of No. 9 soft annealed double-galvanized wire. This was applied by means of two motor-driven cable-wrapping machines, the invention of H. D. Robinson. The ends of each cable band were counter-bored to receive the wrapping wire and were then caulked tightly with lead wool.

The wrapped cable, cylindrical in form and $16\frac{3}{4}$ in. diameter, was given three coats of paint over the galvanized wrapping. The hermetic seal formed by the wrapping is to supplement the protection afforded by the double galvanizing on every wire in the strands composing the cable. The longevity of such cable construction should be practically indefinite.

SUSPENDER ROPES.

Around each cable band, two $1\frac{5}{8}''$ suspender ropes were placed, providing four parts of rope for suspending the steel-work at each truss panel point.

The steel suspender rope, $1\frac{5}{8}''$ diameter, was of 6 x 19 construction with a 7 x 7 independent wire rope center. The specified minimum ultimate strength was 212,000 lbs. per rope, and the elastic modulus was over 14,000,000 lbs. per square inch after pre-stressing.

Each rope was pre-stressed to 100,000 lbs. and held at that tension for $\frac{1}{2}$-hour. The tension was then reduced to the working stress of 35,000 lbs. and the rope was measured under this tension for cutting. The rope was then cut to length, socketed at both ends, and shipped to the site.

FABRICATION OF STIFFENING TRUSSES.

The stiffening trusses, including the floorbeams and lateral system, were fabricated at the Seattle plant of the Wallace Bridge & Structural Steel Company.

The specifications required all splice connections for the trusses to be subpunched and then reamed with the parts assembled.

The side span trusses, each 430 ft. long, were assembled their entire length before reaming their connections.

The main span trusses, 1207 ft. long, were each assembled in three units, and the camber for each unit was carefully checked before the connections were drilled.

ERECTION OF STIFFENING TRUSSES.

The erection of the stiffening trusses was sublet to J. H. Pomeroy Company, Portland. A unique erection method was developed, requiring neither falsework nor traveler.

After shop assembly at Seattle, the trusses were entirely dismantled and the members were shipped to the bridge site. There they were riveted into double panel units, $38\frac{1}{2}$ ft. long, for erection. The side span units were assembled on the ground directly beneath the points for which they were designated. The main span units were assembled on the neighboring Albina Dock, from which they were subsequently carried out on barges for hoisting to position.

FIG. 7.

Stiffening truss erection.

The stiffening truss erection was begun by raising an assembled unit from the barge to position at the mid-point of the main span. This unit consisted of the central two-panel section of the north and south trusses, assembled with the two floorbeams to complete the frame. This assembled unit was picked up at four points (the ends of the floorbeams) by four independent sets of falls.

The fall lines, for raising the truss sections, were hung from wire rope slings around segmental wooden collars lashed to the cables; the cables were wrapped with burlap under the collars.

The hoisting lines were guided parallel to the main cables to the tops of the main towers and then to the drums of steam hoists on the two shores. Six steam winches were used, three on each side of the river.

After the assembled center unit was erected, the subsequent truss sections weighing 10 tons each were raised without the floorbeams. The latter, weighing 7 tons each, were raised later, each floorbeam being picked up at both ends.

After three double-panel sections were erected at the middle of the main span, erection was begun in the side spans, commencing at each cable bent. The truss erection then proceeded at eight points, four in the main span and two in each side span, all progressing toward the main towers.

The wooden collars, around which the fall lines were fastened, were placed about 3 ft. off the cable band. This located the collar directly above the center of gravity of the truss section (which was assembled with the vertical post at one end only).

For shifting the hoisting tackle from point to point, use was made of the upper tramway rope which had been installed for the cable stringing.

After all the truss sections and floorbeams were erected, a second pass was made, in the reverse direction, for placing the stringers and laterals.

The relative erection schedules for the main and side spans were controlled, by alternate lifting, so as to keep the towers within the predetermined permissible deflections.

On February 23, 1931, all steel was in place. Then the floor system and the side span trusses were riveted. The main span trusses could not be riveted until the concrete roadway and sidewalks were placed; this additional dead load was needed to bring the camber down and close the splices.

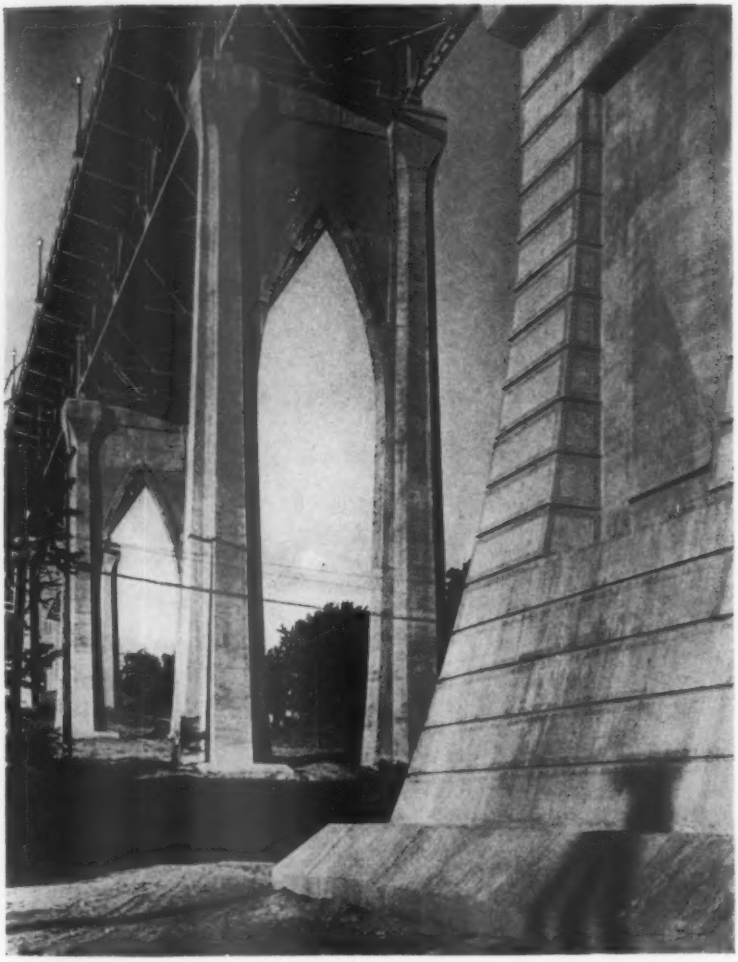
ERECTION OF VIADUCT SPANS.

All erection of the viaduct spans was done by the American Bridge Company.

The three 108-ft. spans, from Pier 1 to Pier 4, were erected with the aid of a single falsework bent placed near the center of each span, and with the use of a jinniwink deck traveler,

with 50-ft. boom, operating on the roadway stringers. The falsework bent was shifted to each successive span as required.

FIG. 8.



Completed viaduct.

For the remaining spans, 144 ft. and 180 ft. long, a timber tower was used, supporting the steel at two panel points at mid-span.

A special cableway, consisting of two parts of 1-in. wire rope, was used to shift the falsework from span to span, also to aid in the erection of some of the steel members in the longer spans.

The truss members were assembled into units, approximately two panels long, and were lifted into position by the traveler.

The entire erection plant, with its novel features, worked smoothly and efficiently.

CONSTRUCTION OF ROADWAY SLAB.

The roadway slab on bridge and viaduct spans was constructed by Lindstrom and Feigenson, Portland. Swigert, Hart & Yett, Inc., delivered 4,100 cubic yards of Transit

FIG. 9.

Roadway completed.

Mix concrete for this contract. The concrete was 1 : 5 mix, with 6.8 bags of cement per cubic yard and 4.95 gallons of water per sack, yielding a minimum strength of 3,700 lbs. in 28 days.

The Transit Mix trucks dumped the concrete into a hopper on the east abutment for the east viaduct and into a hopper on the west bridgehead for the west viaduct. The hopper discharged the concrete into a 2-ton Ford truck having a special body, of 1-yard capacity, divided longitudinally to chute from both sides simultaneously. This truck ran along guides on an elevated wooden runway along the center line of the bridge.

On the bridge spans, the roadway was poured in 38½-ft. panels. The pours were distributed along the span according to a schedule which was planned to prevent excessive deflections of towers and trusses. The truck had to pass over panels of concrete poured the day before, and this requirement was met by interposing pieces of ship-lap between the slab and the runway supports.

The 2067-ft. of suspended span roadway were poured in 8 working days, being completed April 18, 1931.

Agatex, a chemical surface hardener made by the Truscon Laboratories, Detroit, was applied to harden the wearing surfaces of the concrete roadway slabs and sidewalks. It is a white powder, which is dissolved in water and applied with a broom to the slab surface. Two coats are applied at a one-day interval.

CONSTRUCTION OF WEST APPROACH.

The contract for the West Approach, approximately a mile long, included the grading, the construction of the west abutment, the two 36-ft. spans between Piers 14 and 16, and the construction of the Mills Street Bridge. The latter structure involved one 90-ft. and four 30-ft. steel girder spans encased in concrete.

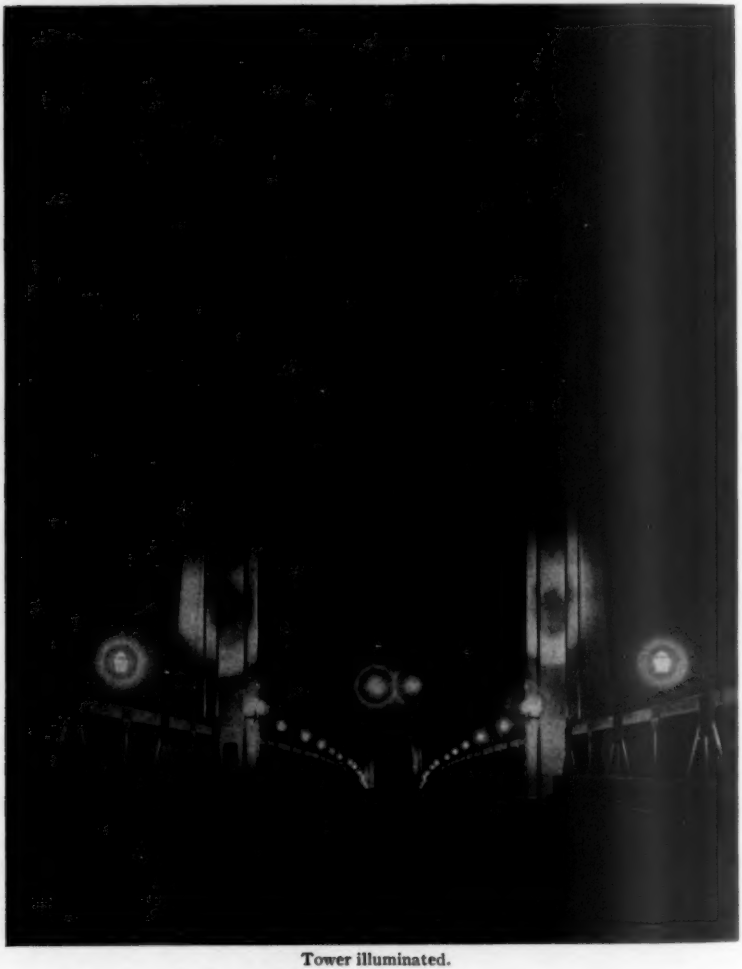
The grading for the road involved 92,000 cubic yards of excavation, of which 56,000 cubic yards was solid rock. This work also involved a large amount of retaining wall construction to hold the fill on the sidehill.

The road was paved with concrete, 30 ft. wide, laid in three 10-ft. strips. A maximum of 1,000 ft. was placed in a day. The concrete was 1 : 5, with 6.8 bags of cement to the cubic yard. The slab was reinforced with wire mesh weighing one-half pound per sq. ft.

BRIDGE LIGHTING.

The roadway lighting is provided by ornamental lighting units spaced at about 80-ft. intervals. These are on two

FIG. 10.



Tower illuminated.

separate circuits, so that one-half of the lights may be used when desired. The outside current is delivered to transformer vaults in the east abutment and the west anchorage, re-

spectively, one lighting circuit being controlled in each. The lights are turned on and off by a Sauter time switch and a self-winding clock with astronomic dial.

Navigation lights are provided to meet the Department of Commerce regulations. Red lights mark the bounds of the channel and green lights mark the center line. The lamps are in double sets, on separate circuits, controlled by Sauter time switches and clocks.

In addition, there are the flashing aviation lights mounted on the tower spires, at the elevation of 400 ft. above mean low water.

For artistic effect in revealing the outlines of the structure at night, inexpensive flood lights have been provided to illumine the towers above roadway level and the cables near the tower saddles. The effect thus revealed is an unusually impressive study in the architecture of structural steel.

ERECTION SCHEDULE.

The rate of progress recorded in the construction of the St. Johns Bridge is shown in the following schedule:

Work commenced	September 3, 1929
Main Piers completed	April 8, 1930
Main Towers completed	August 27, 1930
Cable stringing commenced	October 15, 1930
Cable stringing completed	November 25, 1930
Erection of Suspenders completed	January 2, 1931
Stiffening Truss erection commenced	January 12, 1931
Stiffening Truss erection completed	February 23, 1931
Roadway Slab on suspended spans commenced	April 10, 1931
Roadway Slab completed	April 18, 1931
Sidewalks completed	April 29, 1931
Paving of West Approach Road completed	May 15, 1931
Bridge dedicated and opened to traffic	June 13, 1931
Total period of construction	21½ months

PERSONNEL.

The St. Johns Bridge was designed by Robinson & Steinman, Consulting Engineers, New York City, and was constructed under their direction, with R. Boblow as resident engineer. The work was done under the authority of the Board of County Commissioners of Multnomah County. This Board, at the completion of the work, consisted of Fred. W. German, chairman, Grant Phegley and Frank L. Shull.

CONCLUSION.

The evolution of bridge building has been marked by four successive stages of development: Construction, Analysis, Economics, and Æsthetics.

The pioneer bridge builders had all they could do to cope with the problems of *construction*, devising working methods for sinking foundations and for erecting spans, and depending on empiricism and native judgment for proportioning structures that would stand up.

Then came the progressive development of methods of *analysis*, permitting stresses and sections to be more scientifically determined.

The next stage was the development of the *economics* of bridge design, governing the selection of type of structure, material, form, proportions, sections, and details for maximum efficiency.

The fourth stage, upon which bridge engineers have barely entered, is that of *æsthetic* design. The professional obligation to make bridges æsthetically effective, and the possibility of securing beautiful structures in concrete and steel, are coming more and more to be realized. In the case of steel, it is largely a pioneer problem, demanding all of the resourcefulness, originality, and imagination of the engineer.

The writer trusts that the St. Johns Bridge will be a stimulating contribution to the *æsthetic* phase of bridge design, as well as to the practical, theoretical and economic aspects of bridge engineering.

THE ELECTRIC ARC IN CIRCUIT INTERRUPTERS.*

BY

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ABSTRACT.

It is pointed out that the arc performs useful and necessary functions in circuit interruption and that if the arc is eliminated, other devices which are more expensive and less reliable must be used to carry out these functions. The synchronized interruption of the circuit which the arc effects is considered for the ideal reactive circuit and for the oscillatory circuit. The part which the natural period of the circuit plays in circuit interruption is discussed in some detail. The resistance breaker is discussed.

Arc characteristics for various conditions are discussed. The theory of the high vacuum switch is given. The great effect turbulence has upon the interrupting capacity of arcs is discussed and to this effect is attributed the efficacy of expulsion fuses, oil circuit breakers, the compressed air switch and the expansion breaker. Other proposed theories of the oil circuit breaker, compressed air switch and the expansion breaker are examined. The use of lightning arresters in circuit interruption is discussed.

I. USEFUL FUNCTIONS OF ARC IN CIRCUIT INTERRUPTION.

The fundamental problem of the high power electric switch is the quick suppression of the terrifying and destructive arc which appears spontaneously at the separating electrodes. This problem has been so difficult in the past that the impression is general that the arc is an obstacle and a nuisance which annoyingly intrudes itself and prevents easy control of high power circuits. It is believed that if the arc did not appear of itself, or could be prevented from appearing by some simple means, then the problem of circuit interruption would have an easy and ideal solution.

However, closer scrutiny of the fundamentals involved shows that this impression is altogether false, and that far from being all nuisance, the arc plays a very necessary and useful rôle in circuit interruption and that if the arc did not occur spontaneously it would have been necessary to invent

* Presented at the International Electrical Congress, Paris, 1932.

it or some more expensive and complicated equivalent device to take over its useful functions. Instead of being malicious, nature has really been most kind and beneficent in thrusting upon us the electric arc for use in interrupting high powered circuits.

The useful rôle which the arc plays is intimately bound up with the fundamental laws of electromagnetism, according to which an electric current has accompanying it always a magnetic field and according to which variation in the magnitude in the magnetic field induces electric forces in the conductor carrying the current. There are two aspects to the way in which the arc plays its useful rôle. First, it permits the current to flow in spite of separating contacts. If an arc did not form, so that the current was necessarily reduced to zero at the instant of separation of the contacts, then the sudden collapse of the magnetic field would induce enormously high voltage. The arc which forms prevents the development of such high voltage. In a well designed switch the arc allows the current to be reduced only so fast that dangerously high voltages are not induced.

In the direct current circuit the resistance to flow of current which the arc introduces must be such as to cause the current decrease to zero value. Ultimately, however, at some moment it must actually interrupt the circuit; that is, it must change from being a conductor of finite resistance to being an insulator of practically infinite resistance. Now it is most important that this change from conductor to insulator takes place when the current is close to zero in value. How close will be one of the purposes of this paper to explain. This is the second aspect of the useful functions of the arc. In a well designed switch the arc synchronizes its introduction of high resistance with a moment of close approach of the current to zero value.

This synchronous action of the arc is perhaps more easily understood in the a.c. circuit. Here it is not necessary for the arc to reduce the current to zero. In fact, the current of itself passes through zero twice per cycle. In well designed a.c. switches the arc voltage is generally not large compared to the circuit voltage and the arc influences the approach of the current to zero value in only a minor way. But while

the arc introduces only a moderate resistance to the flow of current, so long as the current is appreciably different from zero, it chooses a time interval of a few microseconds embracing the current zero for effecting its "coup de grace" and actually opening the circuit by developing an infinite resistance.

If it were possible to separate the contacts in an a.c. switch with sufficient velocity precisely at a moment of current zero, then an arc would not form and an arc would not be necessary. At the moment of current zero there is no magnetic field linking the circuit and no magnetic energy which must be dissipated by the switch. Thus no high voltages are induced even though the circuit is instantly opened at the moment of separation of the contacts. But consider the extreme difficulty of the electro-mechanical problem of synchronizing the separation of the contacts with the current zero. Consider the large forces necessary to accelerate and get separated the contacts in so short a time as a few microseconds. Consider the difficulty of controlling these forces so that they accomplish their function precisely at current zero within a few microseconds and remember that for forces of such short duration as a few microseconds solid bars ordinarily thought of as rigid and liquids thought of as incompressible appear highly flexible and highly compressible. Consider the complicated and varied relations which determine what will be a moment of current zero in a power circuit and which make it impossible to start going the forces which are to open the contacts much ahead of the current zero itself. Considering all these things it would seem that the mechanical opening of contacts synchronously with a current zero is well nigh impossible of solution.

The arc relieves us of all these difficulties. We separate the contacts when we please. The arc permits the current to continue to flow. Then at a moment of current zero the arc changes over to an insulator and opens the circuit.

II. THE IDEAL INDUCTIVE CIRCUIT.

How precise must this synchronization with the current zero of the interval of change of the arc from conductor to insulator be? It depends upon the natural period of oscilla-

tion of the circuit being opened. If the natural period is very short, then the synchronization in the a.c. circuit must be very close. If the natural period is very long, then a wide latitude is permissible in the synchronization.

It is instructive to consider the ideal circuit in which perfect synchronization becomes necessary for the a.c. case; that is, the circuit with natural period zero. This will be the circuit containing only inductance in series with the generator and no resistance or shunt capacity. It appears that for this ideal circuit conditions are quite different for the d.c. case and a.c. case. In the former, if the arc resistance is supposed adjusted so that no high voltage is induced when opening a particular current, then a slight change in the time of introduction of this resistance will make only a slight change in the induced voltage. But in the a.c. case a slight change in the time of introduction of the resistance will make enormous changes in the induced voltage. This is because in the d.c. circuit the approach to current zero is determined by the arc resistance itself with the generator voltage opposing the reduction of current, whereas in the a.c. reactive circuit the generator voltage is also causing the current to approach its zero value.

Consider, then, first a direct current circuit in which a generator of voltage E is supplying current to an inductance of L-henries and suppose that at time $t = 0$ when the current is I amperes an arc is introduced, the voltage at whose terminal is e_a so that we have, determining the instantaneous current, the equation

$$L\frac{di}{dt} + e_a = E. \tag{1}$$

We define the instantaneous arc resistance r by the equation

$$e_a = ri. \tag{2}$$

Let us require that the instantaneous voltage on the inductance shall never exceed $2E$ in value and let us suppose that somehow at $t = 0$ we produce an arc (or an invented substitute for the arc) which shall introduce just enough resistance into the circuit to reduce the current at such a rate

as to induce just the voltage $2E$ in the inductance. Then

$$L\frac{di}{dt} = E - e_a = -2E. \tag{3}$$

Hence

$$e_a = 3E, \tag{4}$$

$$i = I - \frac{2E}{L}t, \tag{5}$$

$$r = \frac{3E}{I - \frac{2E}{L}t}. \tag{6}$$

This will be the ideal opening of the circuit where the current is reduced as fast as possible and the energy dissipated in the arc is the minimum compatible with the limit set upon the inductive voltage E_L. This condition is illustrated in Fig. 1a. r becomes infinite and the circuit is opened at

$$t = T = \frac{LI}{2E}.$$

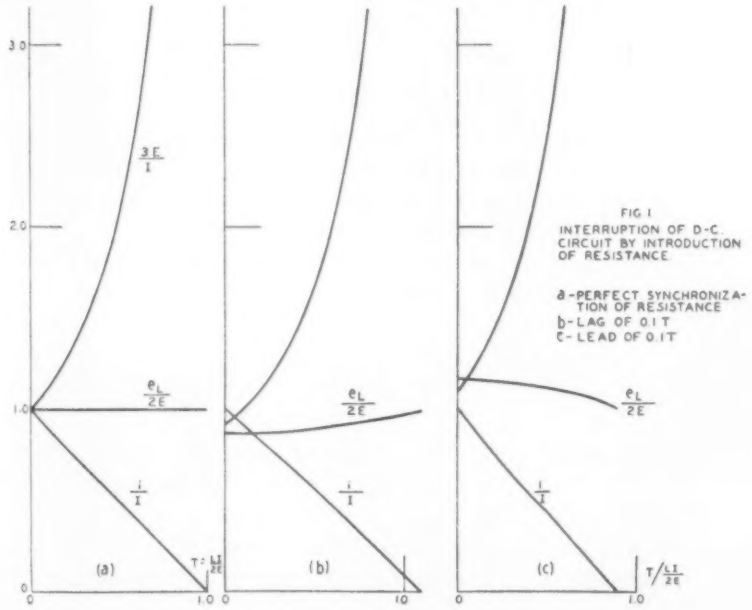


FIG 1
INTERRUPTION OF D-C. CIRCUIT BY INTRODUCTION OF RESISTANCE
a-PERFECT SYNCHRONIZATION OF RESISTANCE
b-LAG OF 0.1 T
c-LEAD OF 0.1 T

Let us suppose now that instead of following equation (6) the arc resistance had lagged behind in time by a definite interval t_1 so that it would be given by

$$r = \frac{3E}{I - \frac{2E}{L}(t - t_1)} \cdot \tag{7}$$

Equation (1) now becomes

$$L\frac{di}{dt} + \frac{3E}{I - \frac{2E}{L}(t - t_1)} i = E, \tag{8}$$

giving

$$i = \left[I - \frac{2E}{L}(t - t_1)\right] - \frac{2Et_1}{L}\left[I - \frac{2E}{L}(t - t_1)\right]^{3/2} \cdot \left[I + \frac{2E}{L}t_1\right]^{-3/2} \tag{9}$$

and

$$e_L = L\frac{di}{dt} = -2E + \frac{6E^2t_1}{L}\left[I - \frac{2E}{L}(t - t_1)\right]^{1/2} \cdot \left[I + \frac{2E}{L}t_1\right]^{-3/2} \cdot \tag{10}$$

The plots of equations (7), (9) and (10) are shown for $t_1 = 0$ in Fig. 1a, $t_1 = 0.1T$ in Fig. 1b, and for $t_1 = -0.1T$ in Fig. 1c. We see that the change in time of introduction of the resistance changes the voltage only slightly.

Let us now consider the a.c. reactive circuit. Here equation (1) becomes

$$L\frac{di}{dt} + e_a = -E \sin \omega t, \tag{11}$$

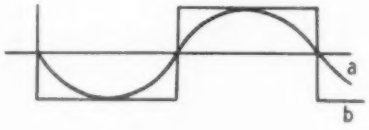
with $i = I$ at $t = 0$.

The essential difference between the a.c. case and the d.c. case is that the generator voltage is negative and is tending to reduce the current in the former, whereas in the latter it is tending to increase the current; that is, the right hand member of (11) is negative, whereas the right hand member of (1) is positive.

There is no essential change in the character of the results if we suppose that the generator voltage is constant in (11) instead of varying sinusoidally and the mathematics is very greatly simplified. This amounts to substituting a square topped wave for the sine wave of voltage as is shown in Fig. 2. The equation (11) then becomes

$$L\frac{di}{dt} + e_a = -E. \tag{12}$$

The author has solved the equations corresponding to (11) graphically and found that the results do not differ in kind from those obtained from equation (12), which we shall use here.



a - ACTUAL SINE WAVE GENERATOR VOLTAGE
b - GENERATOR VOLTAGE USED IN CALCULATION

FIG. 2

Again we assume that the arc introduces resistance only so fast that the instantaneous voltage in the inductance is $-2E$; that is,

$$L\frac{di}{dt} = -E - e_a = -2E, \tag{13}$$

and hence

$$e_a = E \tag{14}$$

and

$$i = I - \frac{2E}{L}t. \tag{15}$$

This gives

$$r = \frac{e_a}{i} = \frac{E}{I - \frac{2E}{L}t}. \tag{16}$$

Let us now suppose that the introduction of the arc

resistance is retarded by a definite time t_1 so that

$$r = \frac{E}{I - \frac{2E}{L}(t - t_1)}. \tag{17}$$

Then (12) becomes

$$L\frac{di}{dt} + \frac{E}{I - \frac{2E}{L}(t - t_1)}\, i = -E, \tag{18}$$

giving

$$i = \left[I - \frac{2E}{L}(t - t_1) \right] - \frac{2Et_1}{L}\left[I - \frac{2E}{L}(t - t_1) \right]^{1/2} \cdot \left[I + \frac{2Et_1}{L} \right]^{-1/2} \tag{19}$$

and

$$e_L = L\frac{di}{dt} = -2E + \frac{2E^2t_1}{L}\left[I - \frac{2E}{L}(t - t_1) \right]^{-1/2} \cdot \left[I + \frac{2Et_1}{L} \right]^{-1/2}. \tag{20}$$

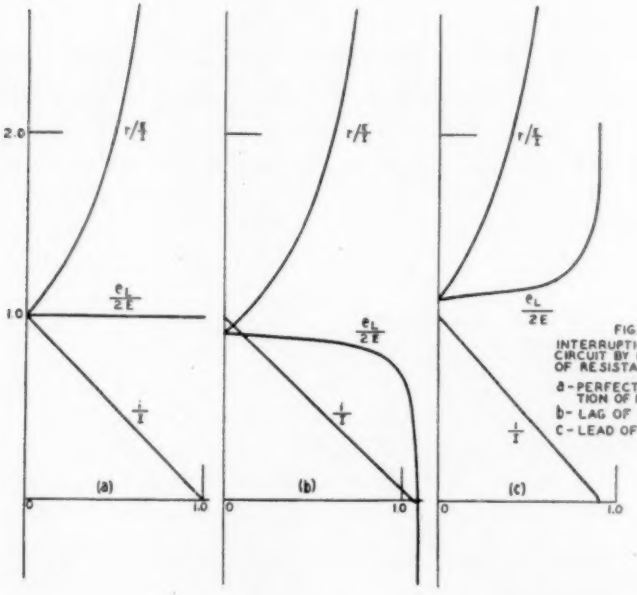


FIG. 3
INTERRUPTION OF A-C CIRCUIT BY INTRODUCTION OF RESISTANCE.
a - PERFECT SYNCHRONIZATION OF RESISTANCE
b - LAG OF 0.1 T
C - LEAD OF 0.1 T

We see at once from (20) that if t_1 is not zero, infinite voltage is induced in the inductance as the current approaches zero. Thus perfect synchronization is required if high voltages are not to be induced. Plots of equations (17), (19) and (20) are shown in Fig. 3a for $t_1 = 0$; Fig. 3b for $t_1 = 0.1T$ and Fig. 3c for $t_1 = -0.1T$ where $T = \frac{LI}{2E}$. Notice that in Fig. 3b the current changes sign and reaches the value $i = -0.0023I$ before the final zero.

III. THE ARC RESISTANCE.

It may seem at first that to speak of the arc as having definite resistance which is an explicit function of the time is purely a mathematical artificiality since frequently the properties of the arc are described by giving a volt-ampere characteristic, thus making the arc resistance a function of the instantaneous current alone and varying in time only as the instantaneous current varies. Thus it might be believed that the arc resistance is necessarily infinite when the instantaneous current is zero. But this is not at all the case for arcs as occur in circuit interrupters. The arc has a real physical resistance which is not dependent on the instantaneous current alone and which is usually not infinite for zero current in the a.c. circuit.

For currents which vary sufficiently slowly the arc has a resistance which is a function of the instantaneous current only, determined by the so-called static characteristic of the arc. This static volt-ampere characteristic is shown diagrammatically as curve (*a*) in Fig. 4. At a particular point P the resistance $\frac{e_a}{i}$ is the slope r_1 of the line joining the origin with the point P. If, however, a high frequency current is superposed on the steady current at P, the static characteristic is forsaken and a new characteristic, the dynamic, is followed as in curve (*b*) in Fig. 4. The resistance of the arc now lags behind the change in the instantaneous current. For very high frequency the dynamic characteristic hugs closely the resistance line r_1 as in curve (*c*) so that the arc has a definite resistance independent of the instantaneous current. Thus the resistance of the arc appears to be a physical quantity which requires time to be changed.

In the language of the ionic theory of conduction in gases, the resistance of the arc besides depending on the temperature, pressure and nature of the gas, is a function of the state of ionization in the arc space and changes as this state of ionization varies. For a point on the static characteristic the activity of the ionizing agents producing ions just equals the activity of the deionizing agents which are removing ions so that the resistance remains constant. For a point below the

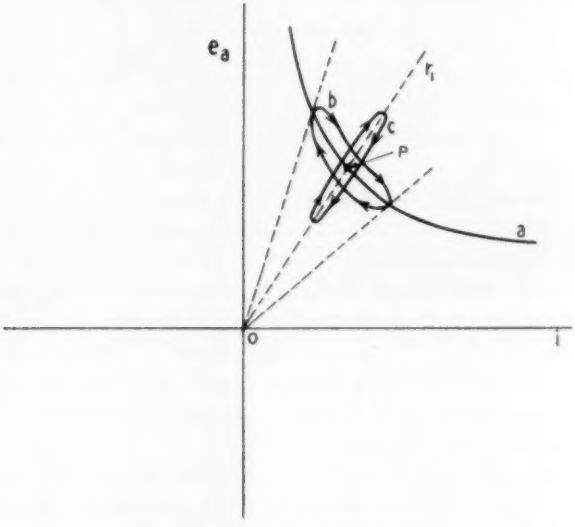


FIG 4:-ARC CHARACTERISTIC

a-STATIC CHARACTERISTIC
b-CHARACTERISTIC WITH SUPERPOSED MODERATELY HIGH FREQUENCY.
c-CHARACTERISTIC WITH SUPERPOSED VERY HIGH FREQUENCY.

static characteristic the activity of the ionizing agents is generally less than the deionizing activity and the resistance increases. The resistance line rotates counter-clockwise towards the voltage axis. For a point above the static characteristic the resistance decreases and the resistance line rotates towards the current axis. For experimentally determined dynamic characteristics with which the diagram of Fig. 4 may be compared, the reader is referred to Seeliger, "Physik der Gasentladungen," Figs. 159, 160, 161, and

"Handbuch der Experimental Physik," XIII, 3 theil, p. 687, Figs. 419 and following figures.

The forsaking of the static characteristic for the dynamic for arcs as are used in switches is really an advantage and not a disadvantage. Otherwise high voltage would always be induced. For example, a one centimeter arc in air of one hundred amperes or more requires less than 100 volts to be maintained. If the static characteristic was followed down to zero current the sparking potential of 30,000 volts would always be reached.

The dynamic characteristic of the arcs assumed in Figs. 1 and 3 are shown diagrammatically in Fig. 5.

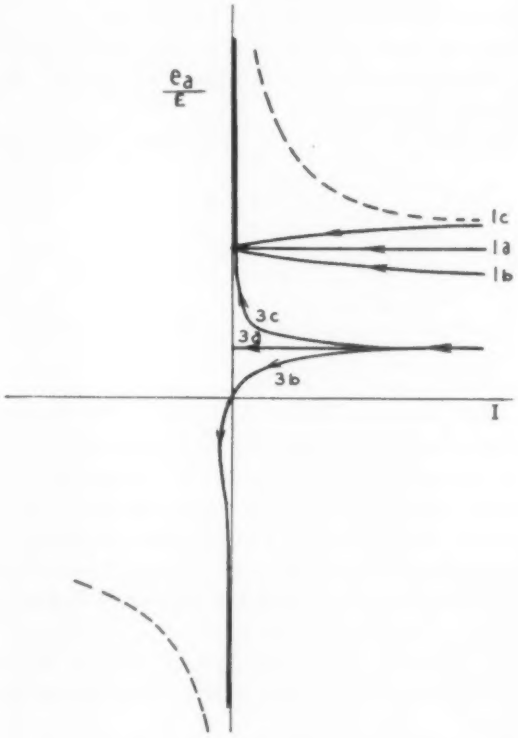


FIG. 5

DYNAMIC CHARACTERISTICS OF FIG. 1 AND 3
----- STATIC CHARACTERISTIC

IV. PRACTICAL OSCILLATORY CIRCUITS. POWER FACTOR AND SYNCHRONIZATION.

Practical circuits differ from the ideal reactive circuit considered in Section II in that they always have distributed electrostatic capacity so that they have a natural period different from zero. The natural period of practical circuits varies from 10 to several thousand microseconds. The finiteness of this natural period is of fundamental importance in the problem of circuit interruption. It eases up the requirements on the arc enormously and eliminates the need for perfect synchronization of the arc extinction as required for the ideal reactive circuit of Section II. The arc resistance may become infinite with reduction of the arc current to zero at any moment and only finite voltage will be induced. If high though finite voltages are to be avoided, synchronization is still necessary, but it need not be precise and a finite time interval is available in any moment of which the arc may become infinite in resistance.

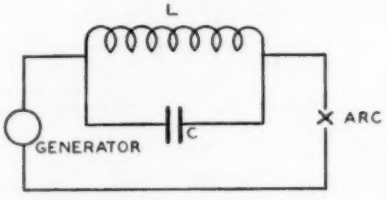


FIG. 6

As typical of the oscillatory circuit we may take Fig. 6 in which an electrostatic condenser of capacity C shunts the inductance L. We may obtain an upper limit to the voltage which may be induced in the inductance L by the rapidly increasing arc resistance r by considering what voltage would be reached if the arc resistance suddenly became infinite at some instant. Suppose then that at a moment when the inductance current is i, the generator voltage e, and the arc voltage e_a, the arc current suddenly becomes zero. In that moment the condenser voltage $e_C = -L\frac{di}{dt} = e_a - e$. An oscillation follows the interruption of the arc current and the maximum voltage will appear across the inductance and the

capacity when all the energy of the oscillatory circuit is momentarily in the condenser. The initial energy in the oscillation is $\frac{1}{2}Li^2 + \frac{1}{2}C(e - e_a)^2$ so that

$$\frac{1}{2}Ce_m^2 = \frac{1}{2}Li^2 + \frac{1}{2}C(e - e_a)^2 \tag{21}$$

or

$$e_m^2 = (e - e_a)^2 + \frac{L}{C}i^2, \tag{22}$$

where e_m is the maximum voltage across the inductance.

For the a.c. case if e_a is neglected in comparison to e, if the moment t is chosen close to a current zero so that $i = -I \sin \omega t$ where I is the peak of the shown circuit current, and if the generator voltage is at its peak E at the moment t,

$$e_m^2 = E^2 + \frac{LI^2}{C}\sin^2 \omega t. \tag{23}$$

Substituting from $\tau = 2\pi\sqrt{LC}$ for the natural period of oscillation and from $E = L\omega I$ and assuming t small so that $\sin \omega t = \omega t$,

$$e_m = E\left[1 + \left(2\frac{\pi t}{\tau}\right)^2\right]^{1/2}. \tag{24}$$

If e_m is to be less than $2E$

$$t \leq 0.276\tau. \tag{25}$$

Thus synchronization of the moment at which the arc resistance becomes infinite does not need to be precise, but has a latitude of about 1/4 of the natural period of the circuit.

If the circuit is such that the power factor is not zero so that the peak generator voltage does not occur at current zero, conditions become still easier. We have then $e = E \sin \theta$ at the moment of current interruption where $\cos \theta$ = p.f. Furthermore, we have at the moment of current zero $L\frac{di}{dt} = -e = -E \sin \theta$ so that near current zero we have $i = \frac{-E \sin \theta}{L}t$. Hence in (22) neglecting e_a we have

$$e_m^2 = (E \sin \theta)^2 + \frac{1}{LC}(E \sin \theta t)^2. \tag{26}$$

Leading to

$$(27) \qquad e_m = E \sin\theta \left[1 + \left(2\frac{\pi t}{\tau} \right)^2 \right]^{1/2}$$

if e_m is to be less than $2E$

$$(28) \qquad t < \frac{1}{2\pi}\left(\frac{4}{\sin^2\theta} - 1 \right)^{1/2} \tau = \frac{1}{2\pi}\left(\frac{3 + \overline{\text{p.f.}}^2}{1 - \overline{\text{p.f.}}^2} \right)^{1/2} \tau.$$

Thus the need for synchronization becomes less as the power factor increases. The following table illustrates this:

TABLE I.

Necessary Synchronization as Function of Power Factor.

Power Factor.	t/τ.
0.0	.276
0.1	.277
0.2	.283
0.3	.294
0.4	.308
0.5	.331
0.6	.364
0.7	.415
0.8	.506
0.9	1.04
1.0	∞

However, if there is to be a very radical change in the needed precision of synchronization a very close approach to unity power factor must be made. Thus if the need of synchronization is to be completely eliminated so that t may be one half cycle of power frequency, say .01 second, and if the circuit is a relatively slow one for which $\tau = 10^{-4}$ seconds so that $\frac{t}{\tau} = 100$, then by (28) the power factor must be 0.9994.

V. THE RESISTANCE BREAKER.

The interruption of power circuits without the use of an arc by introducing other forms of resistance in a continuous manner into the circuit has been a frequent line of attack by inventors. Usually liquid resistances are used and electrodes of special shape are withdrawn or baffles introduced so as to make the resistance vary in the desired way. J. B.

MacNeill [1] in his paper on modern circuit interrupters describes a recent attempt in this direction.

From the preceding sections we conclude that the complete elimination of the arc is practically impossible by this means. If there are to be no excessive voltages induced, an arc must come in to effect the final circuit interruption. The introduction of the resistance and reduction of the current prior to the use of the arc may be of some use since the smaller current arcs are easier to control and yield the desired characteristics with less careful choice and design in the means used to accelerate deionization in the arc. However, if no synchronization whatsoever is made in the introduction of the resistance, reasoning similar to that of the preceding section shows that the current can be reduced only moderately per half cycle if high voltages are not to appear. Roughly, the current can be cut down in any half cycle to half its value in the preceding half cycle. Hence, many half cycles need to be used before the current is reduced to a really negligible value.

With the advances made in recent years in the better utilization of the characteristics of heavy current arcs the author believes that the immediate and direct use of the large current arc in interrupting the circuit will always be cheaper and more practical than the use of the small current arc with the initial modification of the circuit by the introduction of resistance.

VI. EXTINCTION OF A.C. ARCS.

The important part which the natural period of the circuit plays in a.c. circuit interruption has been recognized in recent publications.[2, 3, 4, 5, 6, 7] In the simplified theory there presented it is assumed that the rapid deionization and rise in arc resistance to practically infinite value take place just after current zero in a time less than 1/4 of the natural

[1] J. B. MacNeill, *Electrical Engineering*, Apr. 1931, p. 260.

[2] J. Slepian, *Trans. A. I. E. E.*, **47**, p. 1398, 1928; **48**, p. 523, 1929; **49**, p. 421, 1930; **50**, p. 847, 1931.

[3] J. Biermanns, *E. T. Z.*, **50**, p. 1073, 1929.

[4] F. Kesselring, *E. T. Z.*, **51**, p. 499, 1930.

[5] C. L. Denault, *Elect. World*, **96**, p. 913, 1930.

[6] Attwood, Dow, Krausnick, *Trans. A. I. E. E.*, **50**, p. 854, 1931.

[7] R. H. Park & N. F. Skeats, *Trans. A. I. E. E.*, **50**, p. 204, 1931.

period of the circuit. With our present point of view we see that this is not strictly true. Even before the current zero the resistance of the arc is increasing very rapidly because the ionizing activity is less than the deionizing activity due to the decrease in current. Because of the oscillatory characteristic of the circuit the voltage at the arc terminals cannot rise to the value corresponding to that of the static characteristic which is that value of the voltage at which the ionizing activity just balances the deionizing activity. The discharge is thus not a self-maintaining one, and the resistance is increasing (see Fig. 7). After the current passes through zero

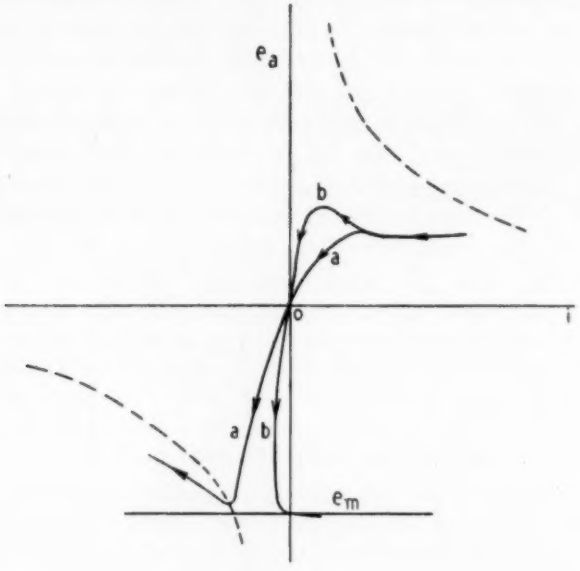


FIG. 7

a - DYNAMIC CHARACTERISTIC OF ARC WHICH IS REIGNITED
b - DYNAMIC CHARACTERISTIC OF ARC WHICH IS EXTINGUISHED
e_a - INSTANTANEOUS ARC VOLTAGE
e_m - PEAK VOLTAGE IN TRANSIENT OSCILLATION OF CIRCUIT
---- STATIC ARC CHARACTERISTIC

the voltage at the arc terminals rises, how fast depending on the transient oscillation of the circuit. If, during the time of this oscillation, the arc resistance has not increased sufficiently, the static arc characteristic will be reached and the arc may reignite (Fig. 7a). If, however, the arc resistance

increases sufficiently rapidly the static characteristic will not be reached and the arc will be extinguished (Fig. 7b).

VII. EXTINCTION OF SHORT A.C. ARCS AT CONSTANT GAS PRESSURE.

There are two general types of cathodes for discharges in gases: the glow cathode and the arc cathode. In the former the current density is low, 10 to 100 amperes per cm.^{2} at atmospheric pressure and varying as the square of the gas density. In the latter the current density is high, several thousand amperes per square centimeter. The glow cathode generally requires several hundred volts for its maintenance. The arc cathode usually requires less than 20 volts. There are thus two static characteristics for discharges in gases, one corresponding to the glow cathode and the other to the arc cathode (Fig. 8). These two characteristics will differ by the several hundred volts required by the glow cathode. For short arcs this difference is important.

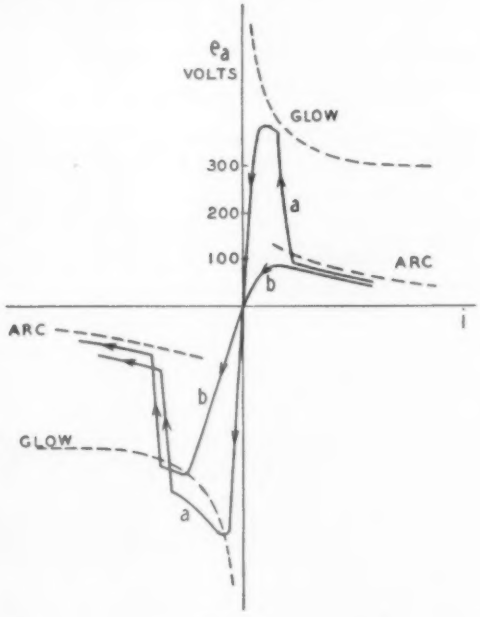


FIG. 8

a-DYNAMIC CHARACTERISTIC OF REIGNITING SMALL CURRENT ARC
b-DYNAMIC CHARACTERISTIC OF REIGNITING LARGE CURRENT ARC
---- STATIC CHARACTERISTIC

At atmospheric pressure, except for very small currents, the glow cathode is unstable and changes over spontaneously into the arc cathode. For cathodes which are not hot enough for thermionic emission this change appears to be discontinuous and fortuitous.[8] For very small currents the arc cathode may be unstable and change spontaneously into a glow.

When the current in the arc reverses, an arc cathode has not yet been formed at the new (incoming) cathode, the current density is low and the discharge must start as a glow which may very shortly after break into an arc. Thus, with electrodes which are not thermionically active, several hundred volts are necessary to restrike the discharge when current reverses.

For small alternating currents the arc may change to glow just before current zero is reached (Fig. 8a). This is the "arc failure" of Attwood, Dow and Krausnick.[4] For large currents "arc failure" does not appear. Figures 7a and 7b also make clear why small currents may take larger voltage to reignite after current zero than larger currents.

VIII. THE VACUUM BREAKER.

An arc is readily struck by separating electrodes even in the highest vacuum. The initial high temperature at the cathode at the moment of separation continues to be maintained by the energy input into the cathode spot of the arc. This high temperature causes volatilization of the cathode and thus supplies the vapor in which the arc plays.

The vapor density, however, is not uniform between the electrodes, but falls off inversely as the square of the distance from the cathode spot, so that if the cathode spot is small the vapor density is low. The vapor density at the anode arising from the volatilization at the cathode spot thus depends on the separation of the anode and cathode as well as upon the current magnitude. In the alternating current arc, due to the thermal lag of the cathode spot the vapor density at the anode depends not on the instantaneous current, but on the previous current so that at current zero there is still a considerable vapor density coming from the hot cathode.

[8] J. Slepian & L. R. Ludwig, *Trans. A. I. E. E.*, 51, 1932.

When the current reverses the discharge restrikes as a glow, but now the gas density at the new (incoming) cathode is rapidly decreasing as the vapor emitting spot on the old cathode cools so that a higher and higher voltage is necessary to maintain the glow until finally the voltage required is greater than the circuit supplies, even for high voltage circuits.

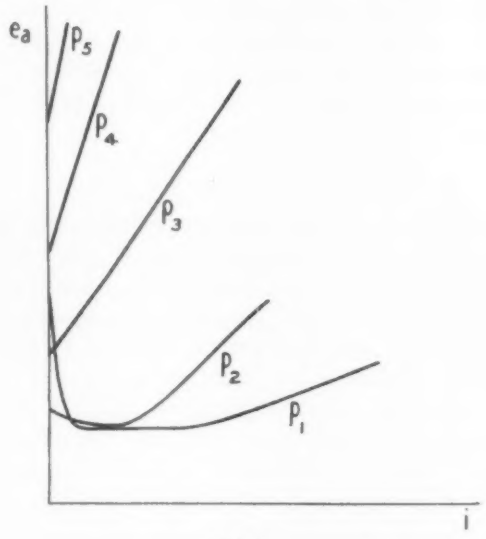


FIG. 9
STATIC CHARACTERISTICS OF GLOW AT DECREASING PRESSURES.
$P_1 > P_2 > P_3 > P_4 > P_5$

In Fig. 9 is shown a family of characteristics of the glow for decreasing vapor densities. Thus is explained the remarkable results obtained in tests on vacuum breakers.[9]

It is clear that the success of the vacuum switch depends on the synchronization of the cooling of the cathode with the zero of current. For large currents the vapor density at the (outgoing) cathode is high right down to current zero so that even if the arc changes to glow just before current zero the voltage required by the glow is not excessive. But for small current arcs, particularly if they happen to be drawn

[9] R. W. Sorensen & H. E. Mendenhall, *Trans. A. I. E. E.*, 45, p. 1102, 9261.

just before the zero of current, the arc may change to glow and the cathode spot cool so rapidly that high voltage will be induced as by Fig. 9.

The greatest difficulty with the vacuum switch, however, is the possibility of a sudden transition from glow to arc during the period that the current is reversed so that the arc reignites. Such transitions occur frequently in mercury arc rectifiers where they are known as "backfires" or 'arc backs." Even in such low voltage devices as these, backfires occur so frequently as to constitute a limitation in design and make necessary larger and less efficient rectifiers than could otherwise be used.[8]

IX. THE A.C. ARC IN TURBULENT GAS.

The most effective and most practical way of increasing the capability of the heavy current arc for circuit interruption is to subject the gas in which the arc is playing to a high degree of turbulent motion. This is most easily accomplished by blowing through the arc space a blast of gas at high velocity. This appears to be the manner of operation of the expulsion fuse, the oil circuit breaker, the compressed air switch and the expansion breaker.[2] In the first two the blast of gas is generated by the direct action of the arc in thermally decomposing solid or liquid material; in the third the gas blast is produced mechanically, and in the last by a combination of the two methods.

How turbulence strongly favors the extinction of a.c. arcs at current zero may be viewed in several ways. First an unconfined arc will tend to take that cross-section at which it can be maintained with the lowest voltage. If it is forced by some means to take some other cross-section, then the voltage required to maintain it will be larger, and its volt-ampere characteristic will lie higher. The effect on the arc voltage of causing the arc to have a smaller section than that which it would assume in the open is well known from studies of arcs confined to cylindrical holes and slots.[2] But it is equally to be expected that if the arc is compelled to assume a larger section, a similar raising of the arc voltage will be obtained. Now arcs as used in switches are generally confined by walls or barriers so that for large currents they

fill the available space and turbulence can have little effect on their cross-section. The turbulence raises the arc voltage it is true, because it brings the ions to the bounding walls where they are lost faster than if they depended on their own diffusion only. But the rise in arc voltage is relatively only moderate, usually not more than five fold for the turbulence caused by gas blast in practical switches. But for small currents where the arc would normally shrink down to a section smaller than that available within the confining walls, the effect of the turbulence is very much greater. The arc is compelled to take a section many times its normal cross-section and the arc voltage is multiplied 10 or 20 fold.

This relative raising of the static characteristic for small currents is of enormous value for circuit interruption. It means that at current zero the rate of increase of resistance of the *dynamic* arc is enormously increased and the arc becomes very much more effective in synchronously opening the circuit.

However, although the turbulence radically raises the cross-section of the arc, it does not seem likely that it leaves it a coherent whole, but more likely that the ionization is not at all uniform over the space section. Another way of describing the effect of the turbulence would be to say that it tears the arc into a large number of parallel arcs. It is well known that if a current is compelled to flow in two parallel arcs, say by means of a balance coil, the arc voltage will be higher than if the current flows in a single coherent arc. Furthermore, from the nature of the volt-ampere characteristic this effect will be greater, the smaller the current.

The violent turbulence will tear the arc into thousands of parallel arcs. Furthermore, if the arc is confined to a limited space, it is clear that a given amount of turbulence will have a greater effect in this way on a small current arc whose natural section is smaller than the available space than on a large current arc which tends to fill this space anyway. Thus, again there is a selective raising of the characteristic for the small currents.

Both ways of viewing the action of the turbulence just given suggest that as the arc approaches small current values the section is caused to depart from normal. In the first

way, the section was considered to be made much larger than normal. In the second way, the section is changed from a single coherent one to that of thousands of filamentary arcs in parallel. Closer study suggests that in the actual extinction of the arc both effects take place and make the arcs still more effective in synchronously interrupting the circuit.

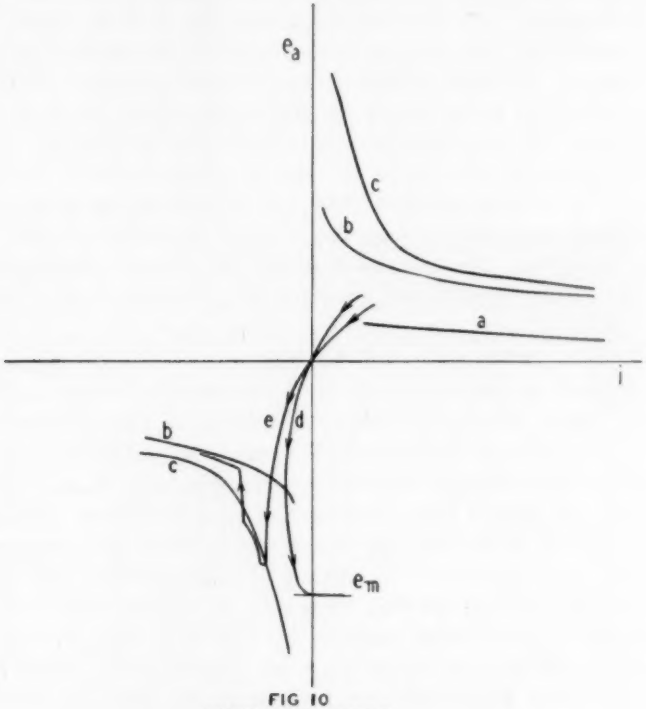


FIG 10
TURBULENT ARCS
a - NON-TURBULENT ARCS
b - TURBULENT ARC, PARALLEL FILAMENTARY ARCS
c - TURBULENT ARC, SINGLE COHERENT SECTION
d - DYNAMIC CHARACTERISTIC OF EXTINGUISHING ARC
e - DYNAMIC CHARACTERISTIC OF REIGNITING ARC
e_m - PEAK VOLTAGE IN TRANSIENT OSCILLATION OF CIRCUIT.

In Fig. 10, curve (*a*) represents diagrammatically the characteristic of a non-turbulent arc. Curve (*c*) represents the characteristic of a turbulent arc, but with the section supposed coherent. Curve (*b*) represents the characteristic when filamentary arcs exist in parallel. Now if the arc takes on the

parallel filament form rather than the coherent cross-section one, it must be because the arc voltage in the former is less than in the latter. That is, with the higher current density in the filaments the ionizing activity at a given voltage is increased so that less voltage is necessary. Hence, curve (*c*) must lie higher than curve (*b*).

Now as the current passes through zero and the voltage is low due to the finite oscillatory period of the circuit, the ions must diffuse out of the filaments and the ionized section becomes a fairly uniform and coherent one, filling the available space. In order to restrike the arc the dynamic characteristic must rise beyond curve (*b*) to curve (*c*). In Fig. 10, (*d*) is the dynamic characteristic of an extinguishing arc and (*e*) that of a reigniting arc. After reaching (*c*), (*e*) may drop back to (*b*), as the parallel filaments strike. Thus, although, as the current decreases, the arc tends to follow characteristic (*b*), during the transient, the arc changes so as to tend to follow characteristic (*c*). Hence, the ratio of the volts which can be interrupted in a circuit of a given period to the volts required by the arc prior to the interruption is greater than if either characteristic (*b*) or (*c*) existed alone. Thus the energy dissipated by the arc for a given circuit interruption is less than if only characteristic (*b*) or (*c*) existed.

Great support to these views is given by researches of T. E. Browne, Jr.[10] By means of magnetic fields this investigator has produced turbulence in arcs and shown the great increase in the interrupting capacity resulting therefrom. The growth of the voltage required for reignition after current zero was studied and was found to be of a form which would be predicted from the idea of ions diffusing out of filaments to a uniform section. The growth of the reignition voltage after current zero of an expulsion fuse was also studied and also found to be entirely similar to that where turbulence in the arc space was produced by magnetic fields without the introduction of fresh gas.

X. OTHER THEORIES; THE OIL CIRCUIT BREAKER.

The popular theory as to the operation of the oil circuit breaker fixes its attention on the dielectric properties of the

[10] T. E. Browne, Jr., *Trans. A. I. E. E.*, 51, 1932.

oil and supposes that the interruption of the circuit is accomplished by the formation of a barrier of oil between the separated electrodes. This theory wholly overlooks the fact established by photographic studies that at least in ordinary oil breakers at the moment of circuit interruption, that is, at the moment of extinction of the arc, both electrodes are in a single continuous gas bubble.[11] The replacing of this bubble by oil takes place long after the arc is extinguished and therefore plays no part in the circuit interruption. The popular theory also overlooks the necessity for close synchronization with current zero of the formation of the oil barrier if high induced voltages are to be avoided.

The interrupting capability of the arc in the oil breaker is far greater than can be accounted for by the nature of the gas, the pressure and the restriction due to the size of the oil bubble. It seems necessary to invoke the effect of the high degree of turbulence introduced into the arc by the intense blast of gas directed into the space arising from the rapid decomposition by the oil bubble walls under the heat of the arc.

Following the popular theory, attempts to improve oil breakers have taken the form of forcing the formation of the oil barrier by means of special devices. Usually attention is centered on the electrodes and efforts are directed towards covering them with a layer of oil. These attempts have generally not been successful in causing the interruption to be affected by the formation of the oil barrier. Increased interrupting capacity of the arc sometimes resulted from the use of these devices due to their effect on bubble dimensions and arc length but the interruption was still by the turbulent arc and not by the oil barrier. When the devices were designed so that they really did interrupt by oil barrier formation, high voltages were always induced due to the impossibility of proper synchronization of the introduction of the oil barrier (see Section XIII).

This line of attack has recently been revived [12] and breakers constructed which are said to operate by the formation of an oil film between the electrodes. An advance in

[11] Wedmore, Whitney, Bruce, *I. E. E. J.*, **67**, p. 557, 1929.

[12] D. C. Prince, *Trans. A. I. E. E.*, **50**, p. 506, 1931.

thought at least over previous attempts has been made in considering what must be the minimum rate of growth of thickness of the oil barrier if it is to withstand the rising voltage impressed on the electrodes by the circuit in its transient oscillation. This rate of growth of thickness is called a velocity and the arrangements used are said to impart this velocity to the oil, but the hydromechanical problem of the formation of the oil film is not considered in sufficient detail to say where in the oil this velocity exists. In fact, any serious study of the hydromechanical problem makes it extremely doubtful if the interruption takes place by the formation of a film at all.

The most convincing evidence that the circuit interruption is not affected by an oil film in these breakers is perhaps that although no attention is paid to the synchronization of the formation of the oil film with a normal current zero, no over-voltages are reported as resulting from the use of these breakers even with small currents. If the mechanical forces in these breakers were sufficiently intense and properly directed so that the oil really did close in on the arc and cut it off, there is no reason why the advancing oil should so time its arrival as to make the cutting off take place within a few microseconds of a normal current zero. Hence high induced voltages would result from the use of these breakers in practical circuits.

XI. OTHER THEORIES; THE COMPRESSED AIR BREAKER.

In compressed air circuit breakers a very high velocity blast of gas drawn from high pressure storage tanks is directed through the arc. The result is an extremely high degree of turbulence which would seem to be sufficient to account for the great interrupting capability of these breakers.

The explanation more often given however, is that the arc is cut by the blast, and that a layer of un-ionized gas from the blast interposes itself between the electrodes just as in the oil film theory in the preceding section. Again as in the oil film theory a minimum growth of the layer, or a minimum velocity of the blast, is said to be necessary.[3]

Arguments against this theory however, are entirely similar to those against the oil film theory. Consideration of

the aerodynamic problem makes unlikely the sudden formation of such a layer. Even if such a layer could form, there is nothing to synchronize its formation so precisely with a current zero as to prevent the development of over-voltages. Further evidence may be found in the relation between interrupting capacity and blast velocity in these breakers which have been published.[13] If the interruption were affected by the formation of the layer with a minimum velocity of growth, then there should be a radical difference in the interrupting capacity below and above this critical velocity of the blast, but published data show no such discontinuity at any velocity.

XII. OTHER THEORIES; THE EXPANSION BREAKER.

In the expansion breaker [4] steam under high pressure is developed by the action of the arc on water and then is suddenly vented through large exhausts or ports. This venting may be expected to cause a blast of gas through the arc just as in the expulsion fuse and the turbulence resulting from this blast seems sufficiently able to account for the interrupting capacity of this device.

The explanation given in the literature on this breaker, however, focuses attention on the fall in temperature in the gas during the expansion of the vapor and sets up the magnitude of this rate of fall of temperature as a criterion of arc extinction. In further explanation of why this rate of fall of temperature is effective, the theory is proposed that, due to the drop in temperature, minute water drops condense on the electrons and ions in the discharged path and make them ineffective for carrying current.

So many arguments can be cited against these theories that they hardly seem tenable. Among these may be mentioned:

(1) The influence of the expansion on the temperature of the gas in which the arc is playing is small compared to the influence of the arc energy input and the loss of energy by radiation and other means which balance the energy input. Thus a temperature fall of 10^{5}° C. per second is said to be produced by the expansion in a breaker.[4] But the electrical

[13] W. B. Whitney, *World Power*, 13, p. 236, 1930.

energy input into the arc, if uncompensated by cooling effects, when calculated with any reasonable assumptions as to current density, electric gradient, vapor pressure and density, gives a rate of temperature rise of much more than $10^{6°}$ C. per second. A slight change in arc voltage therefore more than makes up for the effect of expansion. The rates of rise and fall of temperature in a normal small current a.c. arc not subjected to an expansion may be calculated from the experimental observations of the instantaneous temperature made by Ornstein [14] and comes out more than $8 \cdot 10^{5°}$ C. per second.

(2) The temperatures observed in the a.c. arc, even close to current zero, amount to several thousand degrees [14] and are far above the critical temperature for water. There can be no condensation at such temperatures.

(3) Loading of the ions, if it could occur, would not facilitate their disappearance. Hence deionization at current zero would be hindered and not aided.

(4) Loading of the ions, if it could occur as proposed, would occur while the current was not zero, as well as at zero, since there is no synchronization of the expansion. In fact since the gradients are higher, the loading is less likely to take place during the extinction than at other times. If this loading of the ions stopped the ionizing process at times other than current zero, high voltages would be induced.

(5) Expansion in permanent gases which contain only a small amount of water, as in the fiber expulsion fuse, produced effects comparable with those in the expansion breaker.

XIII. IDEAL ARC CHARACTERISTICS.

The most ideal dynamic characteristic of the arc for a.c. circuit interruption from the standpoint of energy dissipation would be one in which the arc resistance remained very low down to very small currents and then became infinite very rapidly; that is, low until within a small fraction of the natural period of the circuit from a normal current zero and then became infinite within this period. Such a characteristic is shown in Fig. 11a. It is approached by the arc in the high vacuum switch when failure by "backfire" does not occur.

[14] L. S. Ornstein, *Kon. Akad. Amsterdam*, **34**, No. 6, p. 764, 1931.

Another type of ideal characteristic is shown in Fig. 11b. Here the arc voltage remains constant and above the peak value of the circuit for all current values other than zero, but not of so high a value as to endanger insulation. $2E$ might be such a value of voltage. This characteristic is ideal for the d.c. circuit and, in both the a.c. and d.c. cases, interrupts the circuit in the shortest possible time.

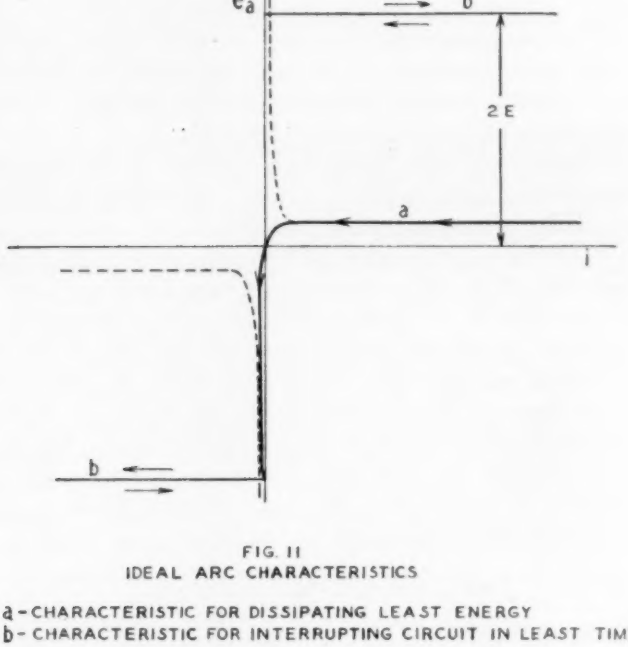


FIG. 11
IDEAL ARC CHARACTERISTICS

a - CHARACTERISTIC FOR DISSIPATING LEAST ENERGY
b - CHARACTERISTIC FOR INTERRUPTING CIRCUIT IN LEAST TIME

This characteristic (Fig. 11b) is precisely the one which is sought for in lightning arresters and is approximately attained in several practical devices used for this purpose. Thus lightning arresters may be used as circuit interrupting devices. Fig. 12 shows an early and successful attempt in this direction. Coincidently with the separation of the contacts, enormous forces on the oil cause the initial arc which is formed to be interrupted by an oil barrier. Since there is

no attempt at synchronization the voltage rises to a value high enough to divert the current through the lightning arrester which completes the interruption of a circuit.

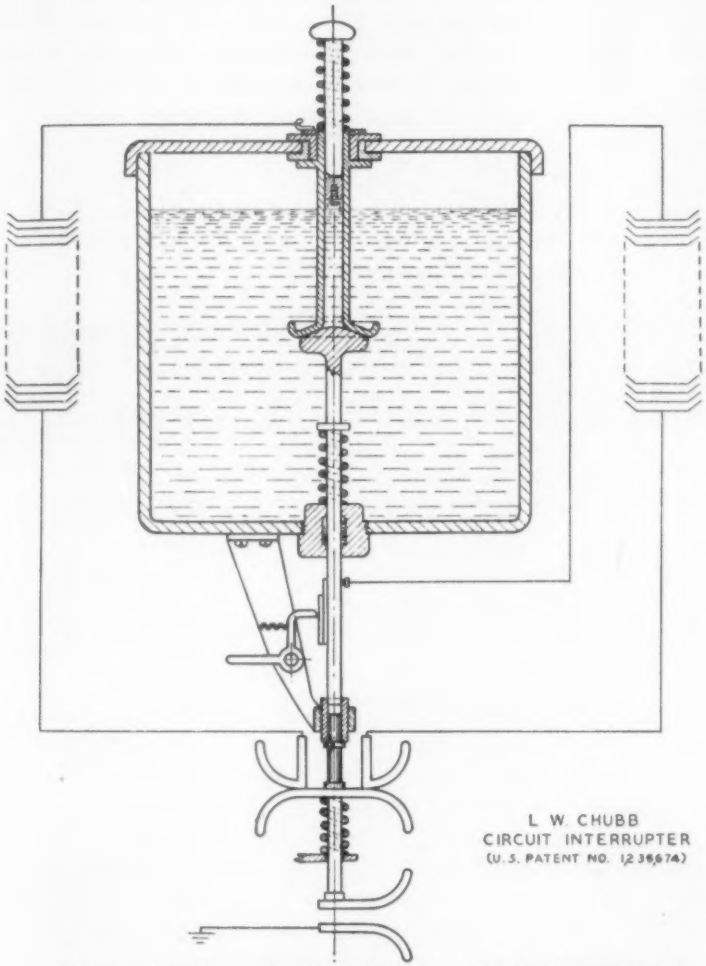


FIG. 12.-USE OF LIGHTNING ARRESTERS IN CIRCUIT INTERRUPTION

It is interesting to notice that available lightning arresters are arc devices, using the word arc to describe discharges in gases in general. The new autovalve arrester uses discharges

confined to fine passages in a porous material. The old autovalve arrester used short glows between electrodes of special material. The thyrite arrester uses large numbers of spark gaps shunted by condensers and resistors. In the old electrolytic arrester, current is passed by myriad sparks between the electrolyte and the coated aluminum plates. None of these arresters however, appears to have sufficient capacity to discharge the short circuit magnetic energy of a high power system without suffering damage. In the old electrolytic arrester, for example, in a test of this kind, the formation of steam threw the electrolyte out from between the trays and the arcing burned holes in the aluminum trays. In the old and new autovalve arresters holes were burned through the materials. While circuit interruption by lightning arresters remains a theoretical possibility, it appears at present that when made with sufficient capacity they are prohibitively large and expensive.

PHYSICS AND THE METHOD OF COINCIDENCES.

BY

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ABSTRACT.

In Part I the Physical Scale and the Coincidences are redefined. Emphasis is laid on the three following properties of the Scale: (1) the dimensional property, B; (2) the ordinal scale-mark property n; and (3) the estimate or uncertainty ϵ. The transformation (in finite differences) between amorphous space and metered space is given by $\xi = nB + \epsilon$, where ξ is a coördinate in amorphous space.

In Part II the transcription of pre-relativity mechanics in view of $\xi = nB + \epsilon$ is indicated. Analogues for the transformation of coördinates and total differentials in amorphous (coördinate) space are given in metered space. A relative scale quantum B_0 *common* to a group of scales (used for allocating a set of points) is emphasized.

In part III the notion of a common scale quantum is introduced in the spacetime continuum, which gives rise to the concept of an algorithmic spacetime scale. The three quantities characterizing this spacetime phase scale are: (1) the *absolute* kinematical quantum B; (2) the ordinal number n which is to be identified with an absolute quantum number and (3) the estimate ϵ.

Throughout emphasis is laid on the *ordinal* property of coincidences with their associated ordinal *integers*, in the formulation of kinematical (and dynamical) laws. It is suggested that to bring out quantum and uncertainty effects, relative or absolute, the three kinematical elements n, B, and ϵ, are to replace the space and time coördinates in current use.

PART I—THE COINCIDENCE DEFINED.

Introduction.—It is generally agreed that the science of Physics arises out of an attempt to calibrate sensation. By the recording of a necessarily finite number of coincidences in a single experiment or series of experiments we have at our disposal data which we fit into codifying mathematical formulæ, and call these formulations the laws of physics. The primary coincidences and those obtained by interpolation and extrapolation from the formulæ, generate in the mind the memory of sensation previously experienced. In cases where it is known that the physical effect would destroy the sensory organ, apparatus is applied from which numbers are recorded, the apparatus in general remaining intact after application.

It thus appears that many of the data of Physics lie quite beyond the limits of direct sensation. Nevertheless, custom, in the past, has attempted to give to the data of ultra-sensory effects the same kind of interpretation as to those of intra-sensory data. The difficulties which threatened to arise from this lack of discrimination have been, to a degree, obviated by allowing the experiment to define the concept.[1] This novel point of view, while welcome on account of its attitude of dynamical acceptance and its stimulation of accurate description of experimental conditions of apparatus and observer, nevertheless threatened to inaugurate a countless number of new concepts, if full account were to be taken of the multifarious arrangement of experimental disposition.

If the concept is to be *completely* defined in terms of experimental disposition we are compelled to place stress primarily on apparatus and its interconnected indicating devices, that is, apparatus and its concomitant scales with their indicators. Thus we are led back from concepts in Physics (which are said to *emerge* from measurement and which may be either macroscopic or microscopic) to the actual experimental procedure on which these concepts are painted. Thus, if experimental *procedure* for obtaining data is called *macroscopic* and if the concepts we build are made to lie ever closer to experimental procedure, we may find it eventually possible to build all of our concepts, both macroscopic and microscopic, so close to experimental procedure that the need for microscopic concepts may become ever less important for purposes of correlation. This leaning to complete macroscopic interpretation is not new. Its usefulness in the past has been somewhat curtailed on account of the extreme mathematical difficulties of codification and computation which are introduced when intermediate concepts, macroscopic or microscopic, are eliminated.[2] However,

[1] See for example, Bridgman: "The Logic of Modern Physics," Macmillan Co., N. Y.

[2] Maxwell's simplification of electromagnetic formularization by the introduction of his field quantities E and H, replacing expressions for pondero-motive forces, is a case in point, for they relieved the Physicist of laborious computational processes which latter were wont to arise when the consequences of "action at a distance" (i.e. elimination of intermediate concepts) were formularized, in a *differential* calculus.

the geometrizing, in finite differences, of Physics, by laying stress on gross matter, in contradistinction to the field seems a worthy goal particularly in those branches of science which attempt to codify the experimental findings of gross matter (as such). This paper is an attempt to proceed toward that goal from a largely geometric-analytic point of view, as it takes form from a kinematic study of direct sensing of macroscopic inertial effects.

We note at the outset that when direct sensation becomes ultra-sensory for one sense, a new sensory organ, with appropriate apparatus, is introduced for purposes of calibration, and from the recorded coincidences of apparatus, the mind imagines as best it can, what (for example) the sensation of hotness would be, if the experimenter were to hold his finger tip in an oxy-acetylene flame. Through necessity, therefore, the temperature of the oxy-acetylene flame is measured by a thermometer, which being energized by the flame gives rise to relative motion between matter; which results in recorded coincidences. Thus the measurement of a temperature and the sensation corresponding to this measurement may have no intimate one-to-one correspondence. Recognition of this fact compels us to fix attention on the processes involved in making a measurement. We thus begin to examine anew three physical entities: first, the scale; second, the sensory organ taking part in the examination of the scale; and third, the agency (such as light or sound energy) whereby the sensory organ becomes conscious of continuously identifiable marks in the scale. Thus our program is to formally study phenomena arising from the interaction between meters and the observer as they are influenced by experimental disposition. (We regard, for example, the introduction of oxygen in a vacuum tube as a modification of apparatus i.e. as a modified ensemble of gross matter subject to measurement by scales and clocks.)

Note on Ensuing Definitions.—The definitions which follow admittedly contain many terms which we leave undefined. Numerous concepts of many kinds are passed over hurriedly. Relations such as greater than and less than; concepts such as one-to-one correspondence are used without elaboration. All these concepts are doubtless capable of much profitable discussion, particularly as they affect the definitions herein.

For our purposes we shall postpone the discussion of the intricacies of the mental processes and philosophical connotations which are wont to arise to reach more quickly the objectives of this paper.

Definition of Scale and Proto-scale.—A scale in physics we define as a finite assemblage of *ordered* points embedded in gross matter capable of interacting with a sensory organ by way of an energizing agency. To each point there corresponds a distinguishing mark of such a nature that two conditions are satisfied:

(*A*) Each distinguishing mark is capable of stimulating through some agency (such as light or sound energy) one or more of the sensory organs.

(*B*) Each distinguishing mark is capable of continued identification.

Further we assert (in view of past experiences with scales) that:

(*C*) To each distinguishing mark there is assigned a *rational* number, such that starting from an arbitrary origin mark, the assigned *rational* numbers become absolutely greater as we proceed away from the origin mark along a continuous line joining the points to which the several distinguishing marks are attached.

(*A*) and (*B*), and (*C*) are two inherent conditions and one arbitrary assignment, respectively, sufficient to define a scale. When an inertial system possesses properties (*A*) and (*B*) only we shall call it a "proto-scale." If we number the marks of a proto-scale according to the scheme outlined in (*C*) directly, or by comparison with a scale, the proto-scale is transformed into a scale.

Definition of a Pure Coincidence.—When a scale and proto-scale are juxtaposed, and when one of the sensory organs is sufficiently stimulated (by an agency capable of stimulating the sensory organ in question), by this juxtaposition so that the observer asserts that a distinguishing mark of the scale has at least one point in common with a distinguishing mark of the proto-scale, and, if as a result of this realization the pre-assigned (distinguishing mark) rational number of the scale is recorded, we have a record of a pure coincidence, or simply a coincidence. When the proto-scale distinguishing mark

stands between two scale distinguishing marks, we resort to the process called estimating. The record of a pure coincidence and its generally attendant estimate can be related to the coördinate in amorphous space; we shall discuss this relation forthwith.

COÖRDINATE SPACE (AMORPHOUS) AND METERED SPACE.[3]

Let B = the number of units of length per distinguishing-mark-interval of a scale. It is, in general, a real number, rational or irrational and is a measure of the coarseness of the scale. In this paper we shall take B as rational to make our analysis conform closely to world wide practice. Let $D = \frac{1}{B}$, the number of distinguishing marks per unit of length.[3] It is a real number and a measure of the fineness of the scale. Let ξ be a coördinate in coördinate (amorphous) space. In this paper we shall discuss *uniform*[4] metered space, defined by the constancy of B. We write, therefore, as the transformation equation between coördinate and metered space (see Fig. 2)

$$\xi = Bn + \epsilon. \tag{1}$$

In (1) n is an integer which gives the *ordinal number* of the scale mark, referred to the arbitrary origin mark. ϵ is to be interpreted as the uncertainty in our scale measurement, since it conceptually determines the position of the proto-scale distinguishing mark from either of two adjacent distin-

[3] In part III we shall distinguish between three types of space: (1) Coördinate (amorphous); (2) metrical, and (3) metered.

[4] One is tempted to write

$$B = f'(\xi) = \frac{d\xi}{dn} = \text{constant.}$$

and

$$\int B dn = \xi = Bn + \epsilon$$

for uniform space, where ϵ is an integration constant. There appears to be no readily definitive or experiential background for these equations and they are consequently to be avoided if we are to cling to macroscopics. The transformation (1) is brought out more clearly by the following example: Suppose a length is measured with an ordinary meter stick whose relative quantum is 0.1 cm. per scale mark interval. Then the length may be transformed by

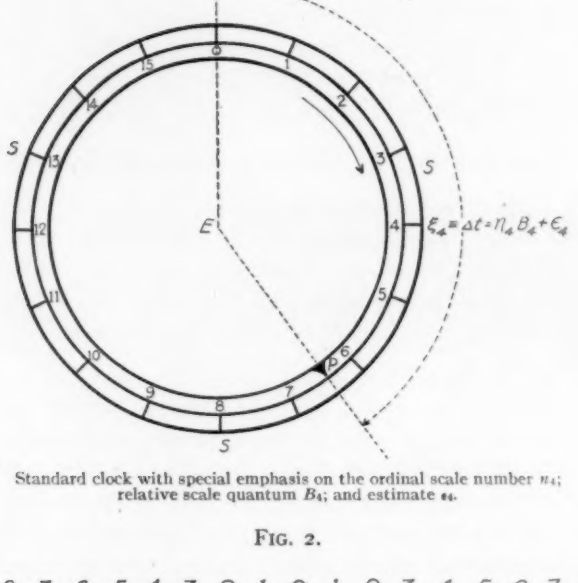
$$\xi = 15.45 \text{ cm.} = 154(0.1) + \tfrac{1}{2}(0.1) = nB + \epsilon,$$

where $n = 154$, $B = 0.1$ cm./scale mark interval and $\epsilon = \frac{1}{2}(0.1)$ cm.

guishing marks, and is not consequently a record of a pure coincidence. It is in fact of the nature of a displacement in coördinate space, which fact may be emphasized by writing

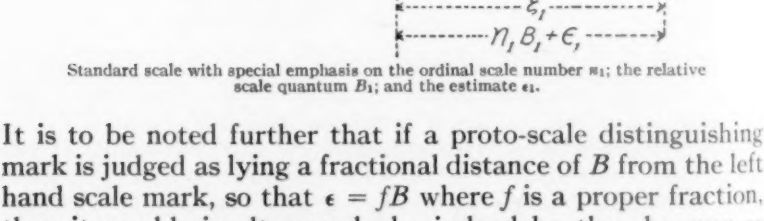
$$\xi - \epsilon = Bn. \tag{2}$$

FIG. 1.



Standard clock with special emphasis on the ordinal scale number n_4; relative scale quantum B_4; and estimate ϵ_4.

FIG. 2.



Standard scale with special emphasis on the ordinal scale number n_1; the relative scale quantum B_1; and the estimate ϵ_1.

It is to be noted further that if a proto-scale distinguishing mark is judged as lying a fractional distance of B from the left hand scale mark, so that $\epsilon = fB$ where f is a proper fraction, then it would simultaneously be judged by the observer as lying $(1 - f)B$ from the right hand scale mark. We make this statement as a first approximation, for the question is a com-

plicated one, as any experimental psychologist can attest. The magnitude of the upper limit of ϵ is B.[5]

In most uniform (B, independent of n) scales used in Physics, the following property is a result of manufacture: If n_1 and n_2 are adjacent scale mark numbers (i.e. scale marks, between which there are no further distinguishing marks), then

$$n_2 - n_1 = \pm \delta$$

is a constant difference and is generally (arbitrarily) taken as unity, i.e.

$$n_2 - n_1 = \pm 1, \text{ anywhere on the scale.}$$

This means that the gauge along a particular scale is invariant, though of course the units explicity given by B need not be. Here n_2 and n_1 are, as has been pointed out, *ordinal* scale numbers.

Mathematical Machinery for the Codification of Physical Laws.—If we recognize that measured physical magnitudes arise, for the most part, from differences between recorded rational numbers, and if further, the independent variable, the ordinal scale number, changes by unity as it does on any ordinary scale, i.e., if

$$n \to n + 1 \qquad \text{or} \qquad n \to n - 1$$

then the formulations in terms of finite differences for both the dependent and independent variables appear to be the natural mode of expression of physical laws arising from the method of recording coincidences.

By means of (1) we can transcribe the formulæ of classical mechanics to formulæ which lay emphasis, through the integer n, on metered coincidences as distinguished from the more abstract concepts which the formulæ of coördinate space imply. This [6] transcription we shall indicate in Part II.

[5] D, the fineness of the scale, is determined entirely by the physical means of distinguishing between two neighboring scale marks. In the field of visual coincidences this can be defined for the several optical devices in use, and gives the resolving power of the same.

[6] This transcription leads us to conclude with Ruark (*Phys. Rev.*, **37**, 315, 1930) that we desire the application of an algebra in which "x is an 'indefinite function' of the 'indefinite variable' t." Applied to Eq. (1) we may think of $\xi = nB + \epsilon$ as the indefinite variable. The algebra in question should emphasize the quantum aspects of the problem in hand through n and B; and the uncertainties through expressions involving ϵ.

PART II—THE TRANSCRIPTION OF PRE-RELATIVITY MECHANICS.

Introduction.—By way of introduction we discuss a simple case. Consider the potential energy of a deformable body obeying Hooke's law. Thus,

$$V = \tfrac{1}{2}kx^2, \tag{1}$$

where $V = 0$ when $x = 0$. (1) states that the intermediate[7] conceptual quantity, potential energy, may be codified in the continuum of coördinate space by the expression $\tfrac{1}{2}kx^2$, where x can take on any real value from zero to positive or negative magnitudes limited only by the condition that k shall be constant. If we wish to emphasize the *means* whereby (1) was set up, we transform according to

$$\xi = nB + \epsilon$$

and find

$$V = \tfrac{1}{2}k(Bn + \epsilon)^2. \tag{2}$$

Consider now two operators $-\dfrac{d}{dx}$ and Δ, where Δ is borrowed from the notation of the calculus of finite differences, and is defined by

$$\Delta U_x = U_{x+1} - U_x,$$

where U_x is the U-function of x. If we apply the first of these operators to (1) and the second to (2) we find

$$-\frac{dV}{dx} = -kx \tag{3}$$

and

$$\Delta V = B^2k\left[(n + \tfrac{1}{2}) + \frac{\epsilon}{B}\right]. \tag{4}$$

Certain important differences are to be noted between the implications of (3) and (4), although both are expressions of *computation* based on experiment. (In (4) $\Delta\epsilon$ is taken as zero, a restriction which will be removed subsequently.) First, while (3) gives the force of restitution at a point x in coördinate space, and has the dimensions of force, (4) gives the increment

[7] Intermediate as distinguished from *directly* conceptual quantities such as the integer resulting from a recorded coincidence.

in energy which *would* take place if the proto-scale distinguishing mark which stands at n were displaced to $n + 1$, and has the dimensions of energy. Second, when $x = 0$, (3) tells us that the deformable body is no longer associated with potential energy, while when $n = 0$, in (4), $\Delta V = B^2k\left[\frac{1}{2} + \frac{\epsilon}{B}\right]$, i.e. the potential energy *would* change by an amount $\frac{1}{2}B^2k$ if the distinguishing mark on the proto-scale were shifted from the origin of the scale to the first scale-mark, with an uncertainty of $kB\epsilon$ in the energy.

Third, if on a particular scale the largest value of n is n_{max}, then

$$\Delta V = B^2k\left[(n_{max} + \tfrac{1}{2}) + \frac{\epsilon}{B}\right]$$

means that the energy change from n_{max} to $n_{max} + 1$ while predicted (with the uncertainty $kB\epsilon$) cannot be directly verified, for the index (proto-scale distinguishing mark) would run off scale in attempting a verification. For off-scale points we go back to (1) of coördinate space. Thus while the range of x is limited only by the constancy of k, an elastic property of the deformable body, the range of n is restricted further by the finite extent of the scale.

In view of (3) and (4) we may state that with the transformation from coördinate to metered space, we emphasize the experimental procedure, i.e. jointly the properties of the body measured as well as the properties of the scale symbolized by B, n, and ϵ.

Time Intervals and the Method of Coincidence.—Consider a sphere of matter E, freed of external forces to the extent that experience can disclose and eliminate forces (Fig. 1). Let this sphere rotate about an axis through E, perpendicular to the plane of the paper. E is a proto-scale and P is a distinguishing mark attached rigidly to this proto-scale. *SSS* is a scale. From the point of view of an observer at rest with respect to this scale, the motion of P is sufficiently distinctive from all other types of motion, that an associated concept arises, a concept called cyclism. If an observer concentrate on a particular coincidence and this coincidence is recorded at least twice, there arises the concept of spatial (coördinate)

cycle. The equality of spatial cycles enhanced by a rhythmic process (which has its origin in the so-called uniformity of the sphere's motion), leads the observer to propose that, associated with the spatial cycle there is, conceptually, another cycle which has to do with duration.[8] This associated concept we call the time cycle. It is frequently desirable to subdivide this time interval into minor time-intervals. From the acceptance of the existence of the uniformity of P's motion with respect to SSS, we agree that the time interval associated with the difference of spatial coincidences characterized by n and $n + 1$, for example, is equal to that associated with the spatial coincidence difference between $n + 1$ and $n + 2$. Thus, from the contemplation of the mechanism of Fig. 1, we introduce the dimension time and call the duration interval between any two successive *identical* coincidences the unit of time and between any two successive coincidences the minor unit of time. (E may be thought of as the earth, P as the cross hair of a telescope, and each distinguishing mark of the scale SSS as the image of the distant star, though in such a representation the observer is thought of as a rest with respect to E.) The apparatus we have just described is a standard clock, with which other clocks may be compared.[9]

Let B_1 be the coarseness of the scale SSS (Fig. 1), i.e. the number of units of length per scale division of the clock scale.

Let B_4 be the number of units of time per scale division of the clock-scale, i.e. more basically the number of units of duration associated with the difference between two successive coincidences of P with respect to SSS. Hence

$$\Delta s = n_1 B_1 + \epsilon_1, \qquad \text{and} \qquad \Delta t = n_4 B_4 + \epsilon_4,$$

[8] It must be remembered that we are attempting to describe a clock without going too deeply into the many metaphysical questions that inevitably arise. We point out here, however, that while the equality of two spatial cycles as such is generally accepted as a self-evident fact, i.e. $\oint ds$ = constant in euclidian coördinate space is invariable for an observer at rest with respect to the scale in question, the equality of intervals of duration is not accepted generally, and, indeed, is realized only in special cases, called uniform rotational motion.

[9] In this part of our treatment, we are ignoring the consequences of the finite velocity of light, i.e. relativity mechanics. Relativity considerations will be treated in part III.

where the subscript 4 refers to the ordinal number of the scale, when used as part of the clock, and the subscript 1 refers to the ordinal numbers when the scale is used as such.[10] Now for the clock $n_1 \equiv n_4$, and since we have to do here with a *single* proto-scale distinguishing mark, $\epsilon_1/B_1 \equiv \epsilon_4/B_4$ (for a single measurement); the velocity of the clock hand tip is

$$\frac{\overline{\Delta s}}{\Delta t} = \overline{v_4} = v_4 = \frac{B_1 n_1 + \epsilon_1}{B_4 n_4 + \epsilon_4} = \frac{B_1}{B_4}.$$

Thus with every clock mechanism there is associated a constant, v_4 (for a given clock-hand length) which may be thought of as its fundamental kinematical magnitude.

Average Velocity.—We now attempt to measure the average velocity of any proto-scale distinguishing mark with respect to any scale of given B_1 employing a clock of given v_4. A proto-scale distinguishing mark P_1 is moving with respect to a scale SS (Fig. 2). Suppose the scale of Fig. 2 is manufactured so that it has the *same* coarseness as the clock scale of Fig. 1. As we shall see later, this particularization does not affect materially the generalization of the points of view about to be developed.

Suppose that when [9, 11] the proto-scale coincidence mark P_1 (Fig. 2) reads $n_1'B_1 + \epsilon_1'$ the clock reads $n_4'B_4 + \epsilon_4'$, and when the P_1 coincidence reads $n_1''B_1 + \epsilon_1''$, then, the clock reads $n_4''B_4 + \epsilon_4''$. Then,

$$\Delta s = \left(n_1'' - n_1' + \frac{\epsilon_1'' - \epsilon_1'}{B_1} \right) B_1$$

and

$$\Delta t = \left(n_4'' - n_4' + \frac{\epsilon_4'' - \epsilon_4'}{B_4} \right) B_4.$$

Between two coincidences (not necessarily adjacent, i.e.

[10] Subscripts 1, 2, 3 will refer to euclidean spatial measurements and 4 to time measurements.

[11] Note that we are passing over without comment the question of simultaneity of the readings $n_1'B_1 + \epsilon_1'$ and $n_4'B_4 + \epsilon_4'$, and $n_1''B_1 + \epsilon_1''$ and $n_4''B_4 + \epsilon_4''$.

$n_2 - n_1 \neq 1$, necessarily)

$$\frac{\overline{\Delta s}}{\Delta t} = \frac{(n_1'' - n_1') + \dfrac{\epsilon_1'' - \epsilon_1'}{B_1}}{(n_4'' - n_4') + \dfrac{\epsilon_4'' - \epsilon_4'}{B_4}} \cdot \frac{B_1}{B_4}. \tag{5}$$

If in an experiment only two space and two time coincidences are recorded the nature of the motion *between* coincidences is not known with certainty. The simplest assumption is that it is uniform.[12] Thus:

1. If when $| n_4'' - n_4' | \geqq 1$, $| n_1'' - n_1' | < 1$, no measurement of velocity is possible. The proto-scale mark P_1 is moving too slowly with respect to the relative-quantum clock velocity.

2. If when $| n_1'' - n_1' | \geqq 1$ and $| n_4'' - n_4' | < 1$ no measurement of velocity is possible. The clock-hand is moving too slowly.

3. If $| n_1'' - n_1' | < 1$ and $| n_4'' - n_4' | < 1$ no coincidence has been recorded.

Therefore, to measure a velocity between two coincidences of P_1 with scale-marks, it is necessary and sufficient that:

$$(a) \qquad | n_1'' - n_1' | \geqq 1,$$

$$(b) \qquad | n_4'' - n_4' | \geqq 1,$$

(a) and (b) holding simultaneously.

From (5) we conclude that the measurement of an average velocity between two coincidences is virtually a comparison of the velocity measured with that of the characteristic velocity, v_4, of a standard clock. Also, that if by measuring a series of coincidences we find that a proto-scale distinguishing mark is moving with "uniform" motion with respect to the marks of a scale, it may be used as a clock.

Momentary Velocity.—It appears that instantaneous velocity, as ordinarily defined, cannot be measured by the method of coincidences. The best approximation that can

[12] In a stroboscopic experiment to determine the velocity of light, we virtually record two coincidences. The nature of the motion of the wave-front is tacitly assumed to be uniform between these coincidences. The assumption of uniform velocity is strengthened by repetition of the experiment with varying distance of light path.

be had, is by arbitrarily setting $(n_4'' - n_4') = 1$ (or alternatively setting $(n_1'' - n_1') = 1$) in (5). Adopting this procedure we define "momentary velocity" by [13]

$$\frac{\Delta s}{\Delta t} = \frac{(n_1'' - n_1') + \dfrac{\epsilon_1'' - \epsilon_1'}{B_1}}{1 + \dfrac{\epsilon_4'' - \epsilon_4'}{B_4}} \cdot \frac{B_1}{B_4}. \tag{6}$$

Average Acceleration.—Consider now the space-time recording of three coincidences in an experiment to determine average acceleration

$$\frac{\overline{\Delta x'}}{\Delta t} = \frac{(n_1'' - n_1') + \dfrac{\epsilon_1'' - \epsilon_1'}{B_1}}{1 + \dfrac{\epsilon_4'' - \epsilon_4'}{B_4}} \cdot \frac{B_1}{B_4},$$

$$\frac{\overline{\Delta x''}}{\Delta t} = \frac{(n_1''' - n_1'') + \dfrac{\epsilon_1''' - \epsilon_1''}{B_4}}{1 + \dfrac{\epsilon_4''' - \epsilon_4''}{B_4}} \cdot \frac{B_1}{B_4}.$$

The average acceleration is given by

$$\frac{\overline{\Delta^2 x}}{\Delta t^2} = \frac{\dfrac{\overline{\Delta x''}}{\Delta t} - \dfrac{\overline{\Delta x'}}{\Delta t}}{(n_4''' - n_4'')B_4 + (\epsilon_4''' - \epsilon_4'') + (n_4'' - n_4')B_4 + (\epsilon_4'' - \epsilon_4')}. \tag{7}$$

Momentary Acceleration.—For "momentary" acceleration

[13] It is interesting to note at this point that (if we make $\epsilon \ll B$ and set it equal to zero) we may write

$$x' = n_1' B_1,$$
$$x'' = n_1'' B_1,$$

so that

$$\Delta x = x'' - x' = (n_1'' - n_1')B_1,$$

where x' and x'' may be thought of as coördinate "states" referred to the same origin of coördinates. Further in view of (6) (with $\epsilon = 0$) we may write

$$v_1' = n_1' v_4,$$
$$v_1'' = n_1'' v_4,$$

so that

$$\Delta v = v_1'' - v_1' = (n_1'' - n_1')v_4,$$

where v_1'' and v_1' may be thought of as velocity "states" referred to the same origin of velocity.

we set $n_4''' - n_4'' = 1$ and $n_4'' - n_4' = 1$, whence $n_4''' - n_4' = 2$. (7) becomes

$$\frac{\Delta^2 x}{\Delta t^2} = \frac{\dfrac{(n_1''' - n_1'') + \dfrac{\epsilon_1''' - \epsilon_1''}{B_1}}{1 + \dfrac{\epsilon_4''' - \epsilon_4''}{B_4}} - \dfrac{(n_1'' - n_1') + \dfrac{\epsilon_1'' - \epsilon_1'}{B_1}}{1 + \dfrac{\epsilon_4'' - \epsilon_4'}{B_4}}}{2 + \dfrac{\epsilon_4''' - \epsilon_4'}{B_4}} \cdot \frac{B_1}{B_4^2}. \quad (8)$$

The foregoing elementary considerations give prominence to the existence of integers on account of the close connection between the kinematical concepts involved and the procedure employed in their measurement.

Transformation of Coördinates.—Consider the transformation in coördinate (amorphous) space:

$$x_i = x_i(q_1, q_2, \cdots q_k, \cdots q_f). \quad (9)$$

The total differential is given by:[14]

$$dx_i = \frac{\partial x_i}{\partial q_k} dq_k. \quad (10)$$

We seek for an expression analogous to (10) in uniform metered space, from the point of view of coincidences. We note, first, that for uniform scales:

$$x_i = n_{x_i} B_{x_i} + \epsilon_{x_i}, \qquad i = 1 \cdots f \quad (11)$$

and

$$q_k = n_{q_k} B_{q_k} + \epsilon_{q_k}, \qquad k = 1 \cdots f, \quad (12)$$

where q_k is a generalized coördinate in coördinate space.

Let us write:

$$\Delta q_k = \Delta(n_{q_k} B_{q_k} + \epsilon_{q_k}) = B_{q_k}\left(\Delta n_{q_k} + \frac{\Delta \epsilon_{q_k}}{B_{q_k}}\right).$$

[14] The Summation convention will be adhered to, unless the context implies no summation.

By the method of coincidences the smallest change we can measure is that of one relative scale quantum, i.e. $\Delta n_{q_k} = 1$. If two measurements are actually carried out $\Delta\epsilon_{q_k}$ gives the change in the estimate when $n \to n \pm 1 \cdot \Delta\epsilon_{q_k}$ ranges between 0 and $\pm 2B_{q_k}$. By retaining the difference $\Delta\epsilon_{q_k}$ in our formulæ we imply that the $\Delta\epsilon_{q_k}$ is a result of two measurements, in contradistinction to a purely computational formula in which $\Delta\epsilon_{q_k} = 0$. Further let us adopt the convention that the symbol Δ operating on the independent integral variable n_{q_k} in (9) and (12) gives unity, while when it operates on the dependent variable it is thought of as giving the *total* difference, i.e. Δn_{x_i} is an integer, not necessarily unity.

We thus transcribe (9) by way of (12) into

$$x_i = x_i\{(n_{q_1}B_{q_1} + \epsilon_{q_1}), \cdots (n_{q_k}B_{q_k} + \epsilon_{q_k}), \cdots (n_{q_f}B_{q_f} + \epsilon_{q_f})\} \quad (13)$$

and replace the operation in coördinate space, namely dx_i, by

$$\Delta(n_{x_i}B_{x_i} + \epsilon_{x_i}) = B_{x_i}\left(\Delta n_{x_i} + \frac{\Delta\epsilon_{x_i}}{B_{x_i}}\right).$$

We shall mean by the symbol $\underset{n_{q_k}}{\Delta}(x_i)$ the finite change in x_i when $n \to n \pm 1$ on the B_{q_k} scale and the estimate changes by $\Delta\epsilon_{q_k}$.

With these conventions in mind, we write the analogue of (10) in metered space, thus:

$$\Delta x_i = B_{x_i}\left(\Delta n_{x_i} + \frac{\Delta\epsilon_{x_i}}{B_{x_i}}\right) = \sum_k \underset{n_{q_k}}{\Delta}(x_i). \quad (14)$$

Now

$$\begin{aligned}\overline{\Delta s}^2 &= \sum_i \overline{\Delta x_i}^2 \\ &= \sum_i \left\{ B_{x_i}^2 \left(\Delta n_{x_i} + \frac{\Delta\epsilon_{x_i}}{B_{x_i}}\right)^2 \right\} \\ &= \sum_i \{\sum_k \underset{n_{q_k}}{\Delta}(x_i)\}^2,\end{aligned}$$

which is a quadratic form in finite differences. Now if all the Bx's are dimensionally homogenous and numerically equal (as one can arrange on the "cartesian scale"), then

$$\overline{\Delta s}^2 = B_0^2 \sum_i \left(\Delta n_{x_i} + \frac{\Delta\epsilon_{x_i}}{B_{x_i}}\right)^2 = \sum_i \{\sum_k \underset{n_{q_k}}{\Delta}(x_i)\}^2.$$

We propose now to introduce a representative scale in terms of which Δs may be *computed*. Thus set

$$\Delta s = \Delta n B_0 + \epsilon \equiv n B_0 + \epsilon.$$

Hence

$$(nB_0 + \epsilon)^2 = \sum_i \{ \sum_k \Delta(x_i) \}^2, \qquad (15)$$

where B_0 is a relative scale quantum for a "cartesian scale" *common*, for purposes of computation, to all coördinate scales satisfying (13). The relationships between $n(\equiv \Delta n)$ and ϵ of the representative scale, on the one hand, and Δn_{x_i}, ϵ_{x_i} of the actual scale, we leave for consideration at a future time. In view of (15) we may state that:

If we have a set of scales for measuring ordinary three-dimensional euclidean space (such as a rectangular space network of meter sticks, or radial rods with attached graduated quadrants, etc.), each scale reading being characterized by the necessary and sufficient measure elements, n_{q_k}, B_{q_k} and ϵ_{q_k}; then for all these sets, there exists a *common* relative scale quantum, B_0 which can be computed from (15), under the conditions that n is an integer and $|\epsilon| < B_0$. We may interpret the existence of this common relative scale quantum as meaning that the several sets of scales may be rigidly interconnected for the allocation of a given array of proto-scale distinguishing marks provided all the ϵ_{q_k} are of just the proper size as to make the transformation (13) or (9) obtain. The particular kinds of scales which may be used for this allocation depends, obviously, on the particular kinds of functions involved in the right hand side of (13). If, on the other hand, euclidean geometry (as some assert) is a science based directly on experience, then the converse of the last statement is apropos. We emphasize the picture of rigidly connected euclidean space scales, with a common relative quantum B_0, for the notion will be extended to the spacetime scale discussed in part III.

It may be noted here that a relative scale quantum has a dimension which depends on the kind of scale used. For example, on a graduated quadrant used for measuring angles, B $(\equiv B_\theta)$ would have the dimension of say, radians per scale mark interval of the quadrant, so that a measured angle θ

would be given by

$$\theta = nB_\theta + \epsilon_\theta.$$

The meaning of (14) will become clearer if we consider for example the simple transformation from rectangular cartesian coördinates to polar coördinates in a plane.

$$x = r \cos \theta,$$
$$y = r \sin \theta.$$

In view of (11) and (12) we write

$$n_x B_x + \epsilon_x = (n_r B_r + \epsilon_r)[\cos (n_\theta B_\theta + \epsilon_\theta)],$$
$$n_y B_y + \epsilon_y = (n_r B_r + \epsilon_r)[\sin (n_\theta B_\theta + \epsilon_\theta)].$$

Now

$$\Delta x = \underset{n_r}{\Delta}(x) + \underset{n_\theta}{\Delta}(x),$$

in which

$$\begin{cases} \underset{n_r}{\Delta}(x) = (B_r + \Delta\epsilon_r)[\cos (n_\theta B_\theta + \epsilon_\theta')], \\ \underset{n_\theta}{\Delta}(x) = (n_r B_r + \epsilon_r)\{\cos [(n_\theta + 1)B_\theta + \epsilon_\theta''] \\ \qquad\qquad - \cos (n_\theta B_\theta + \epsilon_\theta')\}, \end{cases}$$

where

$$\Delta\epsilon_r \equiv \epsilon_r'' - \epsilon_r'.$$

One may write similar expressions for Δy.

Note on Dynamical Aspects.—Velocity transformations and equations expressing the great generalizations of classical dynamics can be worked out in terms of the three scale characteristics n, B, and ϵ. Suffice it to say here, that we can describe coördinate space *chiefly* in terms of integers, n, and relative scale quanta B. The continuum is preserved however by the retention of ϵ.

If in

$$\xi = nB + \epsilon$$

$|\epsilon|$ is arbitrarily set equal to B, then $\xi = (n \pm 1)B = n'B$. Thus the estimate belonging to coördinate space grows until it enters the domain of pure metered space.[15]

[15] The domain of pure metered space in which all the ϵ's from measurement and computation are zero, may be treated by Diophantine equations, since the relationships concerned are between functions of integers.

PART III—QUANTUM SPACE.

Coördinate Space and Metrical Space.—Two kinds of space have been useful in codifying the laws of Physics (*a*) coördinate space, and (*b*) metrical space.

In coördinate space we deal with the geometry of position and the infinitesimal region associated with it. The methods of tensor analysis form a suitable calculus. We may characterize this kind of space by stating that:

$$x^{i'} = \varphi^i(x^1 \cdots x^n) \qquad i = 1 \cdots n \quad (1)$$

are n independent functions of the x's provided

$$J \equiv \begin{vmatrix} \frac{\partial \varphi^1}{\partial x^1} & \cdots & \frac{\partial \varphi^n}{\partial x^1} \\ \cdot & & \cdot \\ \cdot & & \cdot \\ \cdot & & \cdot \\ \frac{\partial \varphi^1}{\partial x^n} & \cdots & \frac{\partial \varphi^n}{\partial x^n} \end{vmatrix} \neq 0.$$

The domain of points for which $J \neq 0$ defines, for our purposes, amorphous space. In this space there is no basis for directly comparing directions at two distinct points, nor is there any immediate basis for the definition of magnitude. These deficiencies are overcome by the introduction of a metric. In metrical space, *length* is defined by way of a space metric

$$ds^2 = e g_{ij} dx^i dx^j, \quad (2)$$

where e is plus or minus, so as to always make $ds^2 > 0$ (unless $e = 0$). Relativists have found the invariant quadratic form of great value in Physics, for the invariant property of ds^2 wielding, as it does, a far flung determinism on the *form* of physical laws of observers in different coördinate systems and in arbitrary relative motion, formulates a sharp challenge to experimental findings.

Metered (Empirical) Space and the Absolute Kinematical Quantum.—Following the lead furnished by (2) we write for the squared element of interval in metered space

$$\overline{\Delta s}^2 = e g_{ij} (\Delta x^i)(\Delta x^j), \quad (3)$$

an indefinite quadratic form in *finite intervals*.[16]

Let us now write

$$\left.\begin{aligned}\Delta x^i &= n^i B^i + \epsilon^i \\ \Delta x^j &= n^j B^j + \epsilon^j\end{aligned}\right\}, \tag{4}$$

whence (3) becomes:[17], [18], [19]

$$\overline{\Delta s}^2 = e g_{ij}(n^i B^i + \epsilon^i)(n^j B^j + \epsilon^j). \tag{5}$$

In Eq. (5) we are confronted with a situation which has many points in common with Eq. (15) part II, i.e. to say, if (3) obtains for sets of scales and clocks for all individual observers, we should expect to find a common kinematical quantum for all observers, provided the several sets of scales and clocks [17] employed measure the same point events in space and time. The requirement is strictly analogous to the rigid interconnection of euclidean space scales for the allocations of points in euclidean space. We thus introduce an algorithmic scale by writing

$$\Delta s = nB + \epsilon,$$

where B is the kinematical quantum common to all observers irrespective of (*a*) the kind of scales (provided (1) obtains) used and (*b*) the kind of relative motion and (5) becomes [17]

$$(nB + \epsilon)^2 = e g_{ij}(n^i B^i + \epsilon^i)(n^j B^j + \epsilon^j). \tag{6}$$

Insistence on the invariance of the quadratic form of *finite intervals*, in much the same manner as relativitists insist on the invariance of ds^2 for a physical problem, leads us to interpret B as an *absolute* spacetime quantum, n as an integer of *ordinal* properties which is to be identified with an absolute quantum number, and ϵ the absolute spacetime uncertainty

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[16] Ruark writes $\overline{\Delta s}^2 = c^2\overline{\Delta t}^2 - \overline{\Delta x}^2 - \overline{\Delta y}^2 - \overline{\Delta z}^2$ for galilean space. *Phys. Rev.*, **37**, p. 323, 1931.

[17] The clocks are to be synchronized according to a definite prescription which will be discussed in another paper. Two identical scales locally matched are assumed to retain identical configurations under transport. *Gauge invariance* is seen to follow fairly automatically from the *ordering* of scale marks.

[18] Eq. (11), (12), part II.

[19] $n^i = n_i$, i.e. in view of the fact that n is an invariant it loses properties of contra- or co-variance.

in the spacetime phase scale measurement. This interpretation revealing as it does an absolute kinematical quantum, denies at the same time the complete quantitization of spacetime, for in general [15] ϵ connects the cells, so to speak, into which measurement tends to separate the spacetime continuum. Thus the continuum is preserved.[20]

We must note carefully a distinct difference between the implications of (6) and (2). For (6) the empirical vector displacement $n^iB^i + \epsilon^i$ (or $n^jB^j + \epsilon^j$) is nothing more than a scale reading or a clock reading. The coefficients g_{ij} are themselves, functions of scale and clock readings. For example, they have to do with temperature readings, pressure readings, or scale readings giving the ratio of a mass of gas of a substance to that of an equal volume of oxygen, both under standard conditions (the molecular weight). The value of $(nB + \epsilon)$ can be computed only where an observer with his scales and clocks may go. (6), therefore, can be extended to cosmic problems only if a scale or clock with an observer can be thus extended. In this respect ds transcends $(nB + \epsilon)$. Thus to state that $(nB + \epsilon)$ is the same for all observers, with scales and clocks synchronized [17] according to a definite prescription, is, in the present state of Physical Science, to state that (6) is limited to terrestrial observation, i.e. observation in our laboratories, relatively at rest or in any type of relative arbitrary motion. Thus two terrestrial observers will find the same kinematical quantum B, if their scales and clocks are properly synchronized, and this through computation or experiment in terms of clock and scale readings.

Recapitulating, then, we have for the spacetime phase scale three characteristics, an absolute quantum B, an integer n, and a spacetime uncertainty ϵ. The dynamical world of Physics, i.e. the observed proto-scales,[21] are to be computed in terms of these three quantities of the spacetime phase scale.

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[20] Clearly $|\epsilon| < B$, in our formulation, for if we should write arbitrarily that $|\epsilon| = B$ then $nB + B = (n + 1)B = n'B$.

[21] A spacetime scale may be roughly represented by a mechanical model of an euclidean space network with a small clock at each corner, all these clocks being synchronized according to a conventional prescription.

PART IV—CONCLUSION.

The principal conclusions to be drawn from the aforegoing sections are these:

1. The mathematical formulation of physical phenomena as generally written do not contain integers and scale quanta explicitly and thus tend to obscure quantum effects, relative or absolute.

2. By laying stress on the method of coincidences, the existences of integers as variables, immediately become prominent, as do the existence of two other scale reading elements, namely the scale quantum B, relative or absolute, and the uncertainty ϵ, which last has to do with the physical limitations in recording an exact coincidence.

3. Quantization, whether relative or absolute is, in general, *not complete*, the incompleteness being frustrated by the presence of the uncertainty elements. This frustration has its uses, for, by it the continuum is preserved.

4. The quantum integer n, in $\xi = nB + \epsilon$ has ordinal significance for the coincidence, whether this coincidence be a euclidean space scale, a time scale (clock scale), or a space-time phase scale.

Iron Content of Vegetables and Fruits.—HAZEL K. STIEBELING (U. S. Department of Agriculture Circular No. 205, 19 pages, 1932) presents data on the iron content of 110 different forms, parts, or varieties of fresh fruits and vegetables, based largely on her own analyses. These foods are divided, with respect to their iron content, into four groups: *Poor* less than 0.00040 per cent. iron, *fair* 0.00040 to 0.00079 per cent. iron, *good* 0.00080 to 0.00159 per cent. iron, and *excellent* 0.00160 per cent. or more iron. The *poor* group consists almost entirely of fruits and fruit juices. The *fair* group contains fruits, seed pods, roots, bulbs and blanched leaves and leafstalks. The *good* group contains potatoes and thick pigmented stalks and leaves. The *excellent* group consists of the immature seeds of the legumes and thin green leaves, and includes: Lima beans, beet tops, broccoli leaves, celeriac leaves, chard, chives, collards, cowpeas, dandelion greens, kale, mustard greens, parsley, English garden peas, spinach, turnip tops, vegetable oyster, and water cress.

J. S. H.

Indium.—(*Ind. and Eng. Chem.*, **24**, 686.) It always is interesting to learn of the increasing availability of some rarer element. W. S. Murray has very interestingly summarized the progress made in preparation of indium and its various possible applications. A careful survey has been made on the indium-bearing ores with the result that attention has been concentrated from the start upon those ores that can be worked most profitably. As a result indium can now be made available in substantial commercial amounts.

Indium is not unlike zinc. It is a white lustrous metal, very soft and ductile; it melts at 155° C. and is said to boil at about 1450° C. Plating with indium alone or in conjunction with other metals may become a commercially valuable practice. A place for this metal is indicated in the automotive, electrical, jewelry, and dental fields.

C.

AN ELECTRON ORBIT IN THE MAGNETIC EQUATORIAL PLANE OF THE EARTH.

BY

W. F. G. SWANN,

Director of the Bartol Research Foundation of The Franklin Institute.

BARTOL RESEARCH FOUNDATION.
Communication No. 69.

The problem of the orbits of electrons in the earth's magnetic field has been treated extensively by Störmer [1] from the theoretical side, and by Birkeland [2] from the experimental side, chiefly in relation to the theory of the aurora. In connection with that problem, the orbit of an electron in the equatorial plane did not assume a role of primary importance, as the main point of interest concerned the possibility of explaining how electron orbits could penetrate to sufficiently low latitudes to coincide with the auroral latitudes. In view, however, of the recent recognition of the possibilities of electron energies much higher than would have seemed reasonable a few years ago, and particularly of the recent experiments by Prof. A. H. Compton on the variation of cosmic-ray intensity with latitude, the problem of electronic motion in the magnetic equatorial plane at zero latitude becomes of importance. The formula for this case is, of course, deducible immediately from the more general case. Since, however, it can be deduced from particularly elementary considerations for motion in the magnetic equatorial plane, it may be of interest to record here a derivation, particularly as the derivation serves to emphasize certain important features.

If r is the radius vector to a point P on a curve, ρ the radius of curvature at P, p the perpendicular distance from the origin to the tangent at P, and r_0 the length of the tangent

[1] Störmer, Carl, *Naturwissenschaften*, **17**, 643–651. The problem has also been attacked by P. Epstein: "Note on the Nature of Cosmic Rays," *Proc. Nat'l Acad. Sci.*, **16**, 658, 1930.

[2] Birkeland, K.: "The Norwegian Aurora Polaris Expedition. . . ."

from the origin to the curve, then, as is well known,

$$\frac{dp}{dr} = \frac{r}{\rho} \quad \text{if} \quad r > r_0, \tag{1}$$

$$\frac{dp}{dr} = -\frac{r}{\rho} \quad \text{if} \quad r < r_0. \tag{2}$$

ρ is to be inserted as positive if the radius vector strikes the curve on its concave side at P and negative if it strikes it on its convex side.

In the case where there is no tangent to the curve from the origin, the formula

$$\frac{dp}{dr} = \frac{r}{\rho} \tag{3}$$

holds for all existing values of r.

If M is the earth's magnetic moment, m the relativistic electronic mass, v the velocity of the electron, e the electronic charge, and H the magnetic-field intensity, since v^2/ρ is the acceleration

$$\frac{mv^2}{\rho} = Hev = \frac{M}{r^3}ev.$$

The velocity of the particle is constant along the path, since the force is perpendicular to the path. Since we are dealing with a particle whose velocity is nearly equal to c, the velocity of light, $v = c$. Moreover, the energy of the particle is $(m - m_0)c^2$ which is very approximately equal to mc^2.
If V is the so-called energy in volts,

$$Ve \times 10^8 = mc^2,$$

where e is in electromagnetic units in both cases. Thus,

$$\rho = \frac{Vr^3 \times 10^8}{Mc}.$$

Hence,

$$\frac{dp}{dr} = \pm\frac{Mc}{10^8\, Vr^2}. \tag{4}$$

For convenience, write

$$\frac{Mc}{10^8\, V} \equiv p_0^2, \tag{5}$$

$$\frac{dp}{dr} = \pm \frac{p_0^2}{r^2}.$$

For $r > r_0$, we use the plus sign

$$p = A - \frac{p_0^2}{r},$$

where A is a constant which represents the value of p at $r = \infty$, when the orbit goes to infinity.

For $r = r_0$, $p = 0$, so that

$$A = \frac{p_0^2}{r_0}. \tag{6}$$

Thus

$$p = p_0^2 \left(\frac{1}{r_0} - \frac{1}{r}\right) \quad \text{for} \quad r > r_0. \tag{7}$$

For $r < r_0$, we have to use the negative sign in (4), and

$$p = K + \frac{p_0^2}{r}.$$

Putting $r = r_0$ at $p = 0$, we find

$$K = -p_0^2/r_0,$$

so that

$$p = p_0^2 \left(\frac{1}{r} - \frac{1}{r_0}\right) \quad \text{for} \quad r < r_0. \tag{8}$$

The minimum distance of approach is p_m obtained by putting $r = p$ in (8). Thus

$$p_m = p_0^2 \left(\frac{1}{p_m} - \frac{1}{r_0}\right). \tag{9}$$

Put $p_m/\rho_0 = x$. Then (9) becomes

$$x = \frac{1}{x} - \frac{p_0}{r_0}. \tag{10}$$

From (10), writing $p_0/r_0 \equiv \eta$, we find

$$2x\frac{dx}{d\eta} + \eta\frac{dx}{d\eta} + x = 0, \qquad \frac{dx}{d\eta} = \frac{-x}{2x + \eta}.$$

Since x and η are positive, x diminishes continually with increase of η, and has its least value for the largest possible value of η, i.e., for the smallest value of r_0. We proceed to find the smallest possible value of r_0.

Put $r = r_0(1 + \epsilon)$. Then, from (7),

$$\frac{p}{r} = \frac{p_0^2}{r_0^2} \frac{\epsilon}{(1 + \epsilon)^2}.$$

Now, for a given r_0, $\epsilon/(1 + \epsilon)^2$ has a maximum for $\epsilon = 1$. The value of this maximum is

$$\left(\frac{p}{r}\right)_{\text{Max}} = \frac{p_0^2}{4r_0^2}.$$

By increasing p_∞ we can diminish r_0 by (6). We can continue to diminish r_0 in this manner so long as $(p/r)_{\max} > 1$. The smallest possible value of r_0 is, therefore, given by

$$\frac{p_0^2}{r_0^2} = 4,$$

i.e.,

$$\frac{p_0}{r_0} = 2. \tag{11}$$

It is of interest to observe that the orbit for which r_0 has this value is perpendicular to the radius vector from the origin at the plane where p/r has its maximum value. This orbit does not go to infinity but takes the course qualitatively shown in Fig. 1, A. However, for a value of r_0 infinitely near to the value for this orbit, we find an orbit which does go to infinity. For, put

$$r_0 = \frac{p_0}{2}(1 + \alpha),$$

where α is a small quantity. Then, on substituting in (7),

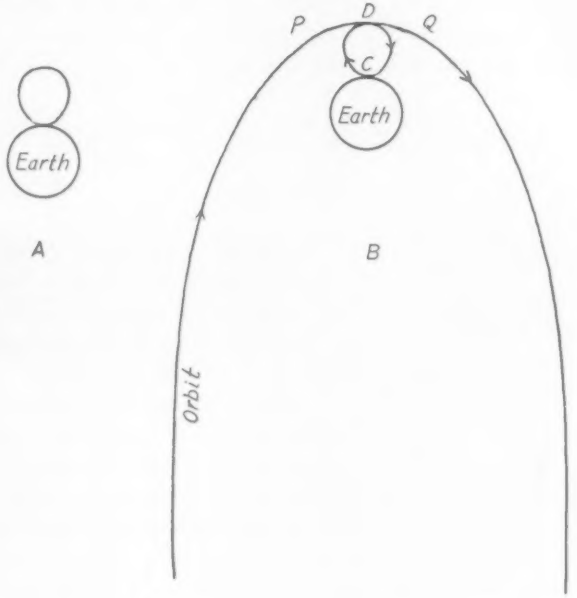
$$p = p_0^2 \left\{\frac{2}{p_0(1 + \alpha)} - \frac{1}{r}\right\}.$$

If we attempt to find a value of r for which $p = r$, we find

$$r^2 - \frac{2p_0}{1 + \alpha} r + p_0^2 = 0,$$

$$r = \frac{p_0}{1+\alpha} \pm \left(\frac{p_0^2}{1+\alpha} - p_0^2 \right)^{1/2}.$$

This is never real for positive α unless $\alpha = 0$. Hence, for r_0, infinitesimally greater than $p_0/2$, the orbit goes to infinity, as in Fig. 1, B, and this orbit gives the minimum distance of



approach for practical purposes. Inserting this minimum value of r_0 in (10) to give the minimum value of x, we find

$$x = \frac{1}{x} - 2,$$

the solution of which is

$$x = \sqrt{2} - 1.$$

Therefore,

$$p_m = (\sqrt{2} - 1)p_0 = 0.41\ p_0.$$

Hence, from (5)

$$V = \frac{Mc}{5.9 \times 10^8\ p_m^2}.$$

Putting p_m equal to R, the radius of the earth, and remembering that the field H_0 at the surface is M/R^3, we have

$$V = \frac{H_0 c R}{5.9 \times 10^8}.$$

Putting $H_0 = 0.31$, $R = 6.4 \times 10^8$, $V = 10^{10}$ volts.

It is of interest to calculate, for this case p_∞, the distance from the origin to the asymptote to the curve at $r = \infty$. Since $A = p_\infty$, for this case, we have

$$p_\infty = \frac{p_0^2}{r_0} = 2p_0 = \frac{2}{0.41} p_m = \frac{2}{0.41} R. \tag{12}$$

$$p_\infty = 5R.$$

In other words, the electron which just grazes the earth's surface is one which at infinity travels along a line whose perpendicular distance from the earth's center is five times the earth's radius. Moreover, as already shown, this orbit is practically perpendicular to the radius vector from the origin at the value of r obtained by putting $p = r$ in (7), i.e., in view of (11), at $r = p_0$, i.e., at $r = 2.5\,R$.

For the case such as is represented by (3) for all values of r, and where the origin lies inside the curve, i.e., for the case where the orbit passes around the earth, but does not make a loop as in Fig. 1, B.

$$p = p_\infty - \frac{p_0^2}{r}. \tag{13}$$

Now p is always less than or at most equal to r. Thus,

$$\frac{p}{r} = \frac{p_\infty}{r} - \frac{p_0^2}{r^2} \leq 1.$$

Put $\frac{p_\infty}{p_0} = \lambda$, and $r/p_0 = y$. Then

$$\frac{\lambda}{y} - \frac{1}{y^2} \leq 1.$$

Now $\left(\frac{\lambda}{y} - \frac{1}{y^2}\right)$ has a maximum for $y = 2/\lambda$; and, for this

value it is equal to $\lambda^2/4$. Hence,

$$\lambda^2 \leq 4$$

and

$$p_\infty \leq 2p_0.$$

Now from (13), the nearest distance of approach is given by p_m, where

$$p_m = p - \frac{p_0^2}{p_m}.$$

Put $p_m/p_0 = x$. Then $x + \frac{1}{x} - \lambda = 0$.

$$x = \frac{\lambda \pm \sqrt{\lambda^2 - 4}}{2}.$$

This gives a real value only if $\lambda^2 \geq 4$. But we must have $\lambda^2 \leq 4$. Hence, the only possibility is $\lambda = 2$, and $x = 1$. In other words, $p_m = p_0$. The orbit in question is none other than the orbit of Fig. 1, B, with the loop missed out. The parts P and Q of the orbit join continuously at the point D for this limiting case, so that both orbits are possible, one with the loop and one without it.

In connection with the foregoing consideration, it is worth while to point out that in considering celestial bodies as the origin of electron rays, one must pay attention to the radiation coming from bodies on the side of the earth remote from that on which we are stationed at the instant.

BARTOL RESEARCH FOUNDATION OF
THE FRANKLIN INSTITUTE,
August 6, 1932.

B & M Remedy.—A trial which lasted more than three weeks at the Baltimore U. S. District Court terminated by upholding the Federal Food and Drug Administration's allegations regarding the falsity and fraudulency in the labeling of " B & M External Remedy " product of a Boston firm, " B & M External Remedy," a liniment composed essentially of water, turpentine, ammonia, and eggs, was labeled with remedial claims for such serious diseases as tuberculosis, rheumatism, influenza, bronchitis, and pneumonia.

The manufacturer claimed that, although the constituents of his preparation were not at all uncommon, when combined in the particular formula employed, they took on some " mysterious power." He brought to the stand some 20 witnesses who claimed to have been cured or benefited by using the liniment in the treatment of tuberculosis, pneumonia, influenza, bronchitis, and other diseases. In return, the prosecution subsequently proved some of the witnesses still to be suffering from the diseases which they claimed the liniment had cured. The Government introduced as witnesses several leading medical authorities, all of whom testified that, according to the consensus of reliable medical opinion, such a product could not possibly have any value in the treatment of the maladies.

C.

Packaged Bees.—(U. S. Dept. of Agriculture, Clip Sheet No. 734.) The package bee business is developing rapidly and promises to inject new life into the beekeeping industry. It provides southern beekeepers an outlet for their surplus bees and northern beekeepers a chance to strengthen their colonies at the beginning of the season. Because of its climate and abundant variety of nectar-secreting blossoms, the South can easily raise more bees than it needs early in the spring. With modern package and transportation facilities, these bees can be shipped North in time to reinforce colonies weakened by the long winter confinement, or even to start entirely new colonies, according to J. I. Hambleton, apiculturist in the U. S. Dept. of Agriculture.

A package recommended by the department is now being adopted by the industry as the standard traveling compartment for bees. It is a cage, 16 by 9 by 5½ inches made of light wood and wire screening. Each cage has a feeder can containing enough syrup for the trip. A 3-pound package of bees may contain about 15,000 workers and a queen. Some up-to-date Northern honey producers are seriously considering the plan of killing all their bees each fall and starting fresh the next spring with package bees.

C.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

COMPARISON OF HIGH VOLTAGE X-RAY GENERATORS.

In medical x-ray practice many different types of high tension generators, such as the mechanical rectifier, kenotron rectifier, or "constant potential" have come into general use. Since the voltage wave forms for these generators all differ, it is not possible by ordinary means to correlate their x-ray emission. Studies have been made in the past showing very large differences between such generators. In recent work at the bureau it was found that such factors as tube enclosure, tube characteristic, and aerial system have a very pronounced effect upon the generator rectification characteristics and hence upon the x-ray emission. These factors were apparently neglected in all earlier studies of this kind.

When controlling the x-ray generator by ordinary means (to give equal peak voltage and average tube current) mechanical rectifiers were found to differ in x-ray output by ± 20 per cent. The quality or penetration of the radiation was likewise found to vary over wide limits. Two mechanical rectifiers, when giving equal outputs for a given filter, were found to give about equal qualities regardless of the peak voltage. A "constant potential" generator operating at some voltage considerably lower than a mechanical rectifier was found, for any given filter and intensity, to have about the same quality as the mechanical rectifiers. Consequently, it is possible to relate directly the outputs of the three generators studied.

In the case of all of the rectifiers, it was found that for equal effective (r. m. s.) voltages applied to the tube, the tube outputs for the same filtration were about equal both as regards quantity and quality. It is thus possible to reduce all radiations to terms of radiation excited by constant potential, which in itself is always characteristic of the voltage.

* Communicated by the Director.

Accordingly "constant potential" radiations may be referred to as a base or a standard, in terms of which all other radiations may be expressed. Effective (r. m. s.) voltages are measured by means of a 150 megohm shielded resistor which does not draw enough current from the generator to disturb its operation.

A more complete discussion of this work will be published as Research Paper No. 475 in the September number of the *Bureau of Standards Journal of Research.*

VOLUME CHANGES IN CERAMIC MATERIALS DUE TO WEATHERING.

In order to obtain some definite knowledge regarding the effect of weathering on the volume of ceramic materials, representative samples of wall tile, terra cotta and dinnerware were selected for observation. The study was begun three years ago when some samples of each kind were subjected to the autoclave test at the Columbus branch of the bureau. A similar group of samples was exposed to actual weathering, while another group was subjected to a moisture saturated atmosphere.

The measurements on the samples exposed to the weather and to the damp atmosphere to determine the percentage increase in length at the end of one year showed approximately the same results as had been obtained in the autoclave treatment, some cases exceeding it and some not reaching it. While the samples exposed to the damp atmosphere showed increases in length much the same as those exposed to the weather, in some cases the increase in length was slightly greater.

The measurements at the end of the second year showed the increase in length in the samples exposed to the weather and in those in the damp atmosphere to be greater than in the autoclave treatment. One exception was noted in each series, however not the same in the two cases.

The measurements at the end of the third year have just been completed. All of the samples showed a further increase in length. Those kept in a damp atmosphere showed a greater increase in length than those exposed to the weather, with two exceptions.

RESISTANCE OF VANADIUM STEEL DIES TO ABRASION BY A PLASTIC SPARK-PLUG PORCELAIN COMPOSITION.

Vanadium "tool steel" dies have been in use by a manufacturer of spark-plugs for extruding blanks from which the porcelain parts of the plugs are formed.

Abrasion tests were made on dies furnished by the spark-plug manufacturer in which the "standard" plastic abrasive material of 60 Maryland clay and 40 glass sand passing 20 mesh was used. These tests were followed by tests in which the plastic porcelain spark-plug composition (all passing 200 mesh) was used as the abrasive medium.

The results obtained with the "standard" abrasive are expressed by the equation $25.21y^{.635} = X$, which represents the relation between abrasion loss "y" in mm.^{3} and extrusion pressure "X" in kg. cm.^{2}

The equation obtained with the porcelain material as the abrasive medium is $159.0Z^{1.155} = X$. At the same extrusion pressure the abrasive "influences" or "intensities" of the two abrasive materials can be compared. Under this condition $159.0Z^{1.155} = 25.21y^{.635}$ or $Z = \frac{y^{.55}}{4.926}$.

At an extrusion pressure of 10 kg. cm.^{2} the comparative abrasiveness of the two abrasive mediums expressed in terms of "abrasion loss" is $Z : y = 1 : 2.557$, while at 50 kg. cm.^{2} extrusion pressure, the relation is as 1 : 8.005.

It appears, therefore, that abrasive loss increases at a more rapid rate as extrusion pressure increases for an abrasive of coarser grain than is the case for an abrasive of finer grain.

In the "standard" abrasive, the effective abrasive material is quartz sand (hardness Moh's scale = 7.0) passing a 20 mesh screen, whereas the effective abrasive material in the porcelain mixture is andalusite (hardness Moh's scale = 7.5) passing 200 mesh in fineness.

"SHORT-TIME" TESTS OF STEELS AT ELEVATED TEMPERATURES.

Metallurgists and engineers in recent years have become thoroughly aware of the fact that much remains to be learned

of the properties and behavior of metals at high temperatures. Modern power plants, petroleum refineries, chemical engineering plants, and many other present day industries must rely in a large degree upon the dependable service of metals at relatively high temperatures.

The problem of the research and testing laboratory is to secure sufficiently dependable data on the strength of metals at high temperatures for the use of the designing engineer. This problem is by no means a simple one, very largely because the strength of metals at elevated temperatures involves a time factor. That is, a metal which appears to be sufficiently strong and rigid when tested to failure by rapid loading at some elevated temperature, may fail at a much lower load if allowed to maintain this load over a longer period of time.

Nevertheless, rapid loading or short-time tests of metals at high temperatures, are of value in securing a general idea of the relative behavior of metals of different composition at those temperatures.

Research Paper No. 474 in the September number of the *Bureau of Standards Journal of Research* reports the results of short-time tensile tests at high temperature for a medium manganese carbon steel, a series of cast nickel-chromium-iron alloys containing 35 per cent. chromium and 10 to 45 per cent. nickel, a series of tungsten-chromium-vanadium steels, and a series of molybdenum-chromium-vanadium steels.

CREEP IN STEELS UNDER LOAD AT HIGH TEMPERATURES.

Today the engineer refuses to resort to the old "cut-and-try" method of designing equipment required to operate at high pressures and high temperatures. He demands definite information regarding the behavior of commercial metals for such service. This demand applies to a variety of properties, but in particular, to the behavior of metals when subjected to fixed loads for long periods of time at elevated temperatures.

The measurement of the "flow" or "creep" of a metal at elevated temperatures for several hundred hours is the nearest approach to a satisfactory test by which materials may be judged for the usual service conditions. Long periods

of time are required to obtain results by this method, which is in direct contrast to the "short-time" test. In the short-time test a tensile test specimen at an elevated temperature is broken in a relatively short period of time by the application of a steadily increasing load. This latter type of test affords preliminary information, with a great saving of time, in the study and development of metals for service at high temperatures.

In Research Paper No. 481, which will be published in the September number of the *Bureau of Standards Journal of Research*, results are given of long-time tension or "creep" tests at different temperatures on two tungsten-chromium-vanadium and a molybdenum-chromium-vanadium steel. These steels were tested as tempered after mechanical working (rolling) and are compared with steels of similar compositions which had been oil-quenched and tempered.

THEORY OF CHROMIUM PLATING.

Chromium plating is now extensively applied on automobiles and household appliances. The solutions are simple and fairly cheap, but the electrical efficiency is low. The purpose of an investigation, recently completed at the bureau, was to develop a theory of the process, in the hope that improvements in it might thereby be promoted.

Although the plating baths consist principally of chromic acid, a small amount of sulphate is also necessary. In this research it was shown that the beneficial effect of the sulphate is caused by the fact that it prevents the formation of an impervious film on the cathode and thus permits metal deposition. It was found possible to explain satisfactorily all the principal facts of chromium plating in terms of this theory and to make certain predictions which were experimentally confirmed. There is, however, no present prospect of any very large increase in the efficiency of this type of bath, but the above theory may aid in the development of other more efficient types.

The complete report of this work will be published as Research Paper No. 476 in the September number of the *Bureau of Standards Journal of Research*.

DETERMINATION OF STABILITY OF PAPER BY HEATING.

The results of a study made at the bureau of some details involved in the technic of making the aging test for paper, in order to improve the reproducibility of the test results, were reported in *Paper Trade Journal*, July 28, 1932.

One of the most convenient methods so far devised for estimating the aging properties of paper consists of measuring the change in folding endurance after the paper has been heated in air for 72 hours at 100° C. and reconditioned. The per cent. retention of folding endurance is taken as an index of the probable life of the paper. Four sources of error influencing the retention value are: (1) lack of homogeneity in the structure of the paper, (2) variations in different folding machines, (3) variations in humidity during testing and (4) variations in oven conditions.

Recommendations were made to minimize the effects of the above mentioned variables. The paper used for the control sample should be as representative of the paper used for the heat treatment as possible. This is accomplished by cutting four folding strips adjacent to one another from 10 representative sheets and using alternate strips for control and heat test samples. It was found that the agreement of the folding endurance of adjacent strips was twice that of strips cut from widely separated areas.

In order to minimize the possibility of errors resulting from testing machine variations and the slight unavoidable departures of the relative humidity from that specified for the testing room, the testing of control and heated strips is alternated so that both are tested on the different machines an equal number of times, and both are equally subjected to the effects of variable humidity.

Samples should be heated in an oven controlled at 100° C. plus or minus 2° C., in which the air is circulated to insure uniform temperature throughout.

With the procedure described the reproducibility of test data is commensurate with the accuracy of the folding test.

CAUSES OF MISREGISTER IN OFFSET PRINTING.

The bureau is coöperating with the Lithographic Technical Foundation in a study of the offset lithographic process. The work was initiated at the request of the Foundation because the industry suffers an annual loss estimated to be 25 per cent. of the theoretical production resulting from a lack of knowledge of the characteristics of paper required for optimum results in printing on the modern high-speed offset press. Preliminary investigation, which included a survey of 31 commercial lithographic plants, revealed that the principal difficulty encountered, in which paper was involved, was misregister of prints. Hence the bureau's work has been confined to a study of the factors influencing the register of prints.

A series of experimental printings were made in a commercial lithographic plant under routine operating conditions to determine what factors influence the closeness of register, and further experimental printings were made to study the influence of the important factors on register. The plant selected was one in which constant atmospheric humidity is maintained, thereby eliminating variability of results due to changing hygrometric state of the surrounding atmosphere. The papers printed were specially prepared by coöperating paper manufacturers, and the history of manufacture was supplemented by laboratory analyses to obtain complete knowledge of the characteristics of the papers for correlation with the results of the printing tests. The papers included samples of machine-finish litho of the same composition prepared with different degrees of hydration of fibers, and different fiber lengths, the same papers surface-sized, coated papers of identical composition differing as to sizing in the uncoated paper, and extra strong machine-finish paper of like composition, differing as to degree of sizing. Information relative to the influence of paper characteristics was obtained in printing the various papers on one press with all other variables minimized, and printing representative samples on a press with controlled variations of such factors as pressure, water, and ink gave data on the effects of press variables.

The results indicate that paper characteristics are important in respect to obtaining register of prints. The papers that had received the least drastic mechanical treatment in

manufacture gave most satisfactory results, and papers that had received the most drastic treatment gave the poorest register, indicating the desirability of manufacturing offset papers with the least beating and jordanning essential for satisfactory strength and finish. Internal sizing was desirable, but the amount used, within normal limits, was not important. Other factors were important. A thorough conditioning of paper to equilibrium before printing the first color is essential and a reasonable seasoning period between printings is desirable. Plates should be standardized in respect to thickness and register marks should be accurately placed. Increase in the amount of pressure used in printing tended to shorten the resultant prints slightly. The amount of water used did not appear important as doubling the normal amount had no serious effect, but the extent of the area covered with ink was important in respect to register.

This work will be fully reported upon in Research Paper No. 480, to be published in the September number of the *Bureau of Standards Journal of Research.*

NOTES FROM THE BARTOL RESEARCH FOUNDATION OF THE FRANKLIN INSTITUTE.

THE BEARING OF THE EARTH'S INTERNAL MAGNETIC PERMEABILITY UPON THE SELF AND MUTUAL INDUCTANCE OF COILS WOUND ON ITS SURFACE.*

BY

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[Abstract.]

Some years ago, the writer[1] discussed in a preliminary form the possibility of obtaining information concerning the internal permeability of the earth from measurements of the self or mutual inductance of cables. On returning to the matter recently, it appeared that the solution of some of the fundamental problems concerned with the matter were simpler than might at first sight be supposed, and such solutions are developed in the present paper. While a very casual inspection of the problem will reveal the orders of magnitude involved, these orders of magnitude may seem rather surprising to one who has not thought about the matter. Thus, to quote a few of the illustrations to be developed later, it may seem rather surprising that the self-inductance of a single circular loop of cable of cross-sectional radius one centimeter, wound around the earth in a small circle of radius half that of the earth has a self-inductance of 80 henries, and that the self-inductance would be increased by a factor of about two if the earth were made of iron. It may seem startling to realize that two parallel circular loops wound on the earth at a distance apart equal to their

* This paper, in its entirety, was published in the *Physical Review*, **41** p. 65, 1932.

[1] "Status, Scope, and Problems of the Section of Terrestrial Magnetism and Electricity of the American Geophysical Union," *Bulletin of the National Research Council*, No. 41, pp. 60–68, 1924.

radius have a mutual induction of 2.8 henries and that, if the earth were replaced by an iron sphere, it would be increased to 11 henries.

Part I of the paper is devoted to a statement of the problems solved, together with the solutions obtained. Part II contains numerical applications, illustrating the results obtained. Part III is devoted to the derivations of the formulæ quoted in Part I.

It will be immediately obvious that many variations of the problem are soluble, and some of these would be of greater service in actual experimental measurements. However, the problems solved have been chosen to illustrate the general principles in their simplest form.

PROBLEMS SOLVED AND FORMULÆ OBTAINED.

The problems solved in the paper comprise:

Problem 1: Deduction of mutual induction of two parallel circular loops of radii b_1 and b_2, respectively, wound on a sphere of radius a and of permeability μ.—The cross section of the wire is negligible in its effect in this case unless the circuits are abnormally close together, and we find for the mutual induction M, in electromagnetic units,

$$M = 4\pi^2 \frac{b_1^2 b_2^2}{a^3} \sum_{n=1}^{\infty} \left[\frac{1}{n(n+1)} + \frac{\mu - 1}{n[n(\mu+1)+1]} \right] P_n'(\nu_1) P_n'(\nu_2), \quad (1)$$

where ν_1 and ν_2 are the cosines of the half angles subtended by the two circles at the center of the sphere, both angles being, of course, measured from a common axis.

Problem 2: Deduction of the formula for the self-induction of a circular loop of radius b wound with wire of cross-sectional radius ϵ upon a sphere of radius a and permeability μ.—The self-induction L in electromagnetic units is

$$L = \frac{2\mu}{\mu+1} L_0 + 4\pi^2 \mu \left(\frac{\mu - 1}{\mu + 1} \right) \frac{b^4}{a^3} \sum_{1}^{\infty} \frac{[P_n'(\nu)]^2}{n(n+1)[n(\mu+1)+1]}, \quad (2)$$

where L_0 is the self-induction of the circle for the case $\mu = 1$, and is given by

$$L_0 = 4\pi b\left[\left(1 + \frac{\epsilon^2}{8b^2}\right)\log_e \frac{8b}{\epsilon} + \frac{\epsilon^2}{24b^2} - \frac{7}{4}\right], \qquad (3)$$

where, moreover, ν is the cosine of the half angle subtended by the circular loop at the center of the sphere of radius a, so that ν is given by $(1 - \nu^2)a^2 = b^2$, and where

$$P_n'(\nu) = \frac{d}{d\nu} P_n(\nu),$$

$P_n(\nu)$ being the Legendre polynomial of degree n.

Problem 3: A circular loop of radius b made of wire of cross-sectional radius ϵ is placed with its plane parallel to and at a distance h above an infinite plane which is the upper boundary of an infinite medium of permeability μ.—The solution has been obtained for the self-induction of this coil as a function of its dimensions and of h and μ. It is found that the self-induction L is given by

$$L = L_0 + \frac{\mu - 1}{\mu + 1} M_{AA'}, \qquad (4)$$

where L_0 is the self-induction of the circular loop in the absence of the medium of permeability μ, i.e., for $\mu = 1$, and is given by (3), and where $M_{AA'}$ is the mutual induction between the circular loop and its image, which is a coil similar to the original coil, symmetrically situated, parallel to it, and with its plane at a distance h below the bounding surface between the two media.

The expression for $M_{AA'}$, the mutual induction of the two coils, is, of course, well known and is given by

$$M_{AA'} = 4\pi b\left[\left(\frac{2}{k} - k\right)E - \frac{2}{k}E\right],$$

where K and E are complete elliptic integrals of the first and second kind to a modulus K, and where

$$k^2 = b^2/(b^2 + h^2).$$

Problem 4: Deduction of the solution for Problem 1 modified

to the case where permeability μ is not constant, but is a function of the distance from the center of the sphere.—The solution of the problem has been outlined for the case of a general functional dependence of μ upon r, and has been carried out in detail for the case where

$$\mu = \left(\frac{a}{r}\right)^m \quad \text{for} \quad r < a,$$
$$\mu = 1 \quad \text{for} \quad r > a.$$

Here m is a positive integer. This form contains as representative a wide generality of cases of increase of μ with different rapidities from unity at the surface of the sphere to infinity at the center. The expression for the mutual induction for this case is

$$M = 4\pi^2 \frac{b_1^2 b_2^2}{a^3} \sum_1^\infty \left[\frac{1}{n(n+1)} + \frac{c_n - n}{n^2(n+1+c)} \right] P_n'(\nu_1) P_n'(\nu_2), \quad (5)$$

where

$$2c_n = m - 1 + (m^2 - 2m + 1 + 4n(n+1))^{1/2}.$$

Problem 5: The solution for Problem 2, modified to the case where the permeability μ is a function of the distance from the center of the sphere.—The problem has been worked out for the variation of μ with r assumed in Problem 4, and the self-induction for this case is given by

$$L = L_0 + \frac{4\pi^2 b^4}{a^3} \sum_{n=1}^\infty \frac{c_n - n}{n^2(n+1+c_n)} [P_n'(\nu)]^2, \quad (6)$$

where L_0 is the normal self-induction of the loop in the absence of the sphere.

Limiting cases for $\mu = \infty$. It is of interest to compare some of the results for the limiting case $\mu = \infty$ with those for $\mu = 1$. Thus, for the mutual induction of the two coils discussed in Problem 1, we have

$$M_{\mu=\infty} = 4\pi^2 \frac{b_1^2 b_2^2}{a^3} \sum_1^\infty \left[\frac{1}{n^2+n} + \frac{1}{n^2} \right] P_n'(\nu_1) P_n'(\nu_2),$$
$$M_{\mu=1} = 4\pi^2 \frac{b_1^2 b_2^2}{a^3} \sum_1^\infty \left[\frac{1}{n^2+n} \right] P_n'(\nu_1) P_n'(\nu_2), \quad (7)$$

so that, clearly, the presence of the sphere of infinite permeability more than doubles the neutral induction.

For the self-induction of a single loop, we have, from Problem 2,

$$L_{\mu=\infty} = 2L_0 + 4\pi^2 \frac{b^4}{a^3} \sum_1^\infty \frac{[P_n'(\nu)]}{n^2(n+1)}, \qquad (8)$$

$$L_{\mu=1} = L_0.$$

Hence, the self-induction is more than doubled by the presence of the sphere of infinite permeability.

For the case of the circular loop, placed at a distance h above the surface of a medium of permeability μ (Problem 3), we have

$$L_{\mu=\infty} = L_0 + M_{AA'}, \qquad (9)$$

where, as before, $M_{AA'}$ is the mutual induction between the coil and its image.

NUMERICAL ILLUSTRATIONS.

In Tables I to IV, which are self-explanatory, numerical examples corresponding to the foregoing formulæ are given. They are calculated for the case of a sphere of radius equal to that of the earth in those problems where a sphere is involved.

TABLE I.

Mutual Induction of Two Parallel Circular Loops Wound on Earth of Permeability μ.

Details of Problem: Radius of earth = 6.4×10^8 cm. Loops of equal radius, parallel to each other and separated by a distance equal to their radius. In other words, Radius = separation = 5.7×10^8 cm.

	1	2	4	9	∞
M (henries)	2.82	4.59	6.73	8.53	11.02

TABLE II.

Self-Induction of Circular Loop Wound on Earth of Permeability μ.

Details of Problem: Radius of earth = 6.4×10^8 cm. Radius of loop = 3.2×10^8 cm. Radius of cross section of wire = 1 cm.

	1	2	4	9	∞
L (henries)	79.8	107.9	131.1	149.0	167.4

TABLE III.

Alteration of Self-Induction of Circular Loop Situated Over and Parallel to a Plane Below Which Permeability is μ.[2]

Details of Problem: Radius of circle b = 1000 cms. The self-induction for the case μ = 1, for the case where the cross-sectional radius of the wire is 0.5 cm., is L_0 = 99.6 micro-henries.

h	h/b	Alteration in Self-Induction in Micro-henries.			
		$\mu = 2$	$\mu = 4$	$\mu = 9$	$\mu = \infty$
100	0.1	7.16	12.89	17.19	21.49
500	0.5	1.65	2.97	3.95	4.94
1000	1.0	0.47	0.85	1.14	1.42
5000	5.0	0.01	0.01	0.02	0.02

[2] The values of the alteration of self-induction for other values of b, but for the same values of h/b, are to be obtained by multiplying the results here given by $b/1000$.

TABLE IV.

Mutual induction M of two parallel circular loops wound around the earth of radius a, for the case where μ varies with the distance r from the center according to the law $\mu = (a/r)^m$, also self-induction of a single loop. The dimensions of the coils are as in Tables I and II.

m	Vaue of a/r for which μ = 10.	Mutual Inductance (henries).	Self-Inductance (henries).
3	2.15	6.76	85.6
2	3.16	5.53	83.7
1	10.00	4.13	81.7
0	—	2.82 [3]	79.8 [3]

[3] This value corresponds, of course, to the case where the sphere has unit permeability throughout.

THE ISOTOPIC WEIGHT OF H^2.*

The mass of neutral H^2 was measured as 2.01351 $\pm$ 0.00006 referred to He and 2.01351 $\pm$ 0.00018 referred to O^{16} = 16. The equivalent packing fraction of H^2 is 67.5 parts in 10,000. On the assumption that the nucleus is composed of two protons and one electron the energy of binding is approximately 2×10^6 electron-volts. If the H^2 nucleus is made up of one

* Abstract of a paper presented before the New Haven Meeting of the American Physical Society on June 23, 1932 by Kenneth T. Bainbridge. The complete paper will appear in the October 1st issue of the *Physical Review*.

proton and one Chadwick neutron of mass 1.0067 then the binding energy of these two particles is 9.7×10^5 electron-volts.

H_3^{1+} and He^+ provided the dispersion measurements for these spectra. The presence of H^1H^{2+} can only introduce in the mass determination a possible *maximum* error of 0.00003 mass units.

Lines of mass 4.02852 on the spectra were attributed to $H_2^1H^2$ ions because (1) no lines of comparable intensity appeared in this position when commercial hydrogen of low H^2 content was used. (2) Under the conditions existing in the discharge tube the abundance of H_2^{2+} was negligibly small compared to the abundance of $H_2^1H^{2+}$, (3) the mass is less than the mass of H_4^{1+} by an amount outside of the limits of error. Two enriched samples of hydrogen prepared by Brickwedde were used, both of which had been tested spectroscopically by Urey and Murphy, and one of which was identical with Bleakney's sample III.

Using the value for the mass of H^2 the energy balance is calculated for one process of non-capture disintegration of N^{14} by neutron impact suggested by Feather which would result in C^{12} and H^2. It is concluded that this disintegration could not possibly occur under the conditions of his experiments.

The Flight of Forest Fires.—(U. S. Dept of Agric. Clip Sheet No. 735.) According to GEORGE M. JEMISON of the Forest Service forest fires are not the slowest things on earth, particularly when conditions are favorable to their spreading. The fire cited as an example took place in Idaho last August at a period when the duff in the forest was unusually dry. Starting at 10:30 one morning this fire in a single day burned over a tract 5 miles wide and 11½ miles long. At the beginning the wind was blowing 12 to 13 miles per hour and its velocity increased to 17 or 18 m.p.h. during the afternoon. Thirteen and one half hours after the fire's inception 640 men were fighting it and not until three days later was the fire brought under control.

C.

Expensive Leaks.—(U. S. Dept. Agric. Clip Sheet No. 735.) Engineers of the U. S. Department of Agriculture remind us that water leaking from a faucet in a stream the size of a common pin wastes about 150 gallons a day. A leak of about 1 drop per second amounts to about 4 gallons a day. While the householder may pay no attention to such leaks, they are invariably noticed by the water meter.

C.

Air-Conditioned Insect Abodes.—(U. S. Dept. Agric. Clip Sheet No. 735.) Most of us have heard of Coddling Moths and now the U. S. Department of Agriculture tells about coddling parasites. These parasites are reared in a laboratory and then taken to the orchard where they can prey upon the oriental fruit moth, a destructive foe of fruit growers. Many of these adult parasitic insects will not stand being shipped a considerable distance in hot weather. To prevent the bad effects of the necessary long, hot trips the Government entomologists at the Moorestown, N. J. station have devised a refrigerated container which seems to keep the parasites healthy and comfortable through a 50-hour journey. Wooden cages having a capacity of 300 cubic inches and holding about 500 oriental fruit moth parasites are packed with dry sphagnum moss in a metal cylinder with a tight-fitting telescopic lid. The cylinder is placed in a 40-quart ice cream shipping tub, which is then filled with sawdust and cracked ice.

C.

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Dr. George F. Kunz, New York City, N. Y.
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BOOK REVIEWS.

ÉTALONS PHOTOMÉTRIQUES, Tome II, Troisième Section, Photometrie Visuelle, de l'Encyclopedie Photometrique. Par Pierre Fleury, Professeur a la Faculté des Sciences de l'Universite de Lille. Preface par M. Charles Fabry, Membre de l'Institut. xii—122 pages, 16 x 24 cms., cloth, Paris, Revue d'Optique theorique et instrumentale, 1932. Price 25 francs.

Standards of illumination have followed in some respects the course of standards of length upon which, even today controversy still persists. Apart from the strict technical merits of the subject, habit and sentiment have had some influence in the matter. We are long accustomed to the yard and want to keep it, sometimes forgetting that the original is insufficiently definable in terms of the capabilities of modern measurement. By the same token, for generations we had become accustomed to candle-light as a unit of illumination, the candle which could be bought at the general store or corner grocery, and illuminated the mansion of the aristocrat as well as the modest home of his commonplace neighbor. So in these

times of adequacy and refinement in the art of illumination, we still retain the candle unit, but as a derived unit like our yard which is now defined in terms of the meter, a more precisely reproducible and available standard.

The author describes those standards which have been employed in the past and have finally been abandoned for the incandescent electric lamp which seems to have supplanted all others in recent times. The advantages of this standard, an arbitrary prototype from which working standards may be calibrated, and the technique of its use are discussed at considerable length. The end of the book, or rather the latter half, takes up an examination of the field of black body radiation and its promising application in furnishing a natural standard of illumination. A review is made of the notable investigations to that end and are yet in progress including an account of the author's own contributions. The book is highly informative on the past and current practice, and future possibilities in achieving a satisfactory photometric standard, and is unusually well documented.

L. E. P.

MODERN MATERIALS HANDLING, by Simeon J. Koshkin, M.E. (Ingenieur E.C.P., Paris, France) Assistant Professor Machine Design, Cornell University. Member American Association for the Advancement of Science. vii–488 pages, 15 x 23 cms., cloth. New York, John Wiley & Sons, Inc., 1932. Price $6.00.

The problem of handling the material which enters into the finished product of a factory, or a structure in the field, is a vital and even critical matter in keeping the balance on the right side of the ledger: wasteful handling can easily entail serious loss. The author states it is estimated that only from 30 to 40 per cent. on the average of the total time employed in manufacture is applied in actual processing, and quite frequently only from 15 to 20 per cent. The value of a didactic text on the subject is accordingly at once obvious.

The work is highly diversified in scope. It treats and analyzes modern methods of handling different kinds of materials and deals with principles and considerations involved in a proper choice of the method of handling any kind of material. The author provides a scheme of classification as an illustration of a more or less systematic way in which materials-handling equipment may be presented, but he points out that they may not be rigidly applied and must be used with discrimination. There are necessarily in one type of materials-handling equipment elements which occur in other types. Nevertheless, the author appears to have found a satisfactory grouping of topics that will appeal to a reader who is familiar with the fundamental types of these devices. The book is copiously illustrated, mostly by half-tone cuts, both of apparatus and installation in operation. Many of the devices are time-honored more or less standardized forms in the dress of up-to-date design and power-equipment, but many late developments are described, particularly in conveying apparatus. The analytical features are duly set forth, the powering of apparatus, costs of installation and operation and expected advantages. Bibliographical references are given in foot-notes.

Both designing engineers and those of field-activities will find the book of rare value as a reference manual while the student will find in it a safe guide in intricacies of a vital feature of manufacturing operations.

LUCIEN E. PICOLET.

INTRODUCTION A L'ETUDE DE LA MÉCANIQUE ONDULATOIRE, par Louis de Broglie, Maitre de Conférences a la Sorbonne, Lauréat du Prix Nobel de Physique, 1929. xvi–292 pages, 15 x 23 cms. Paris, Librairie Scientifique, Hermann et Cie, 1930. Price, in paper, 85 francs.

Those who have been fortunate enough to read Professor de Broglie's *Ondes et Corpuscules* will find the preparation derived from the perusal of that general survey of rare value in approaching the detailed evolution of undulatory mechanics which is analyzed in the present treatise. The author's object is to show how the transition from the classical mechanics to the new mechanics is made and to explain why this transition entails important modifications of our fundamental conceptions on the nature of physical laws, modifications which arise essentially from the *principle of incertitude* of Heisenberg.

The work begins with a summary of the laws of classical mechanics in which particular stress is laid on those features which are of importance in the developments which follow. The fundamental idea of undulatory mechanics, in which with every corpuscle in uniform rectilinear motion should be associated the propagation of a plane monochromatic wave, is then explained according to the same method which made it possible for the author to discover this relation between wave and corpuscle. In order to generalize these ideas in the case of a corpuscle in non-uniform motion, an outline is given of the laws which govern the propagation of waves. These laws permit a ready derivation of the equations of propagation of the wave associated with a corpuscle and, finally, of the most general equation of propagation which is applicable to the case of variable fields as well as constant fields and a null field.

When a wave associated with a corpuscle is propagated according to the laws of geometrical optics, it is shown how its phase coincides with the classical function of Jacobi, and the square of its amplitude is a measure of the density of a cloud of corpuscles. Outside of the field of geometrical optics, one should maintain the import of probability in relation to the density of a cloud of corpuscles. It is this relation which has emphasized the value of those notable experiments on the diffraction of electrons which have established the value to physics of the new theory. The investigations of Davisson and Germer, G. P. Thompson and others which bear on this feature, are examined in considerable detail. Further, it is explained how the statistical significance of the associated wave leads to a visualization of a "cloud" of probability, and it shows why it is difficult to consider the corpuscle as describing a well-defined trajectory. Having proved that these conceptions apply as well to corpuscles of light, photons, as to material corpuscles, the author shows how they lead to the principle of incertitude of Heisenberg and the new *indeterminist* conception of physics. The principle of incertitude is examined fully, both in relation to a train of waves in a null or a uniform field. The extension of the principles which have been established for a single corpuscle are then applied to a collection of corpuscles which entails a consideration of their mutual reactions. Again, after a summary review of former methods of quantification, the author describes the method of Schröedinger and some of its applications. Finally, it is shown how the principles previously discussed can be applied to systems of quantifical atoms.

L. E. P.

LA THEORIE DE LA QUANTIFICATION DANS LA NOUVELLE MECANIQUE, par Louis de Broglie, Professeur a la Sorbonne, Laureat du Prix Nobel. xxviii–250 pages, 15 x 23 cm., paper. Paris, Hermann et Cie. Price 70 francs.

Coming close to the ultimate capacity of trained minds for subtile logic, it is only by that repeated scrutiny of previous deduction and experimental fact that the all-embracing principles of modern physical science may become an obvious truth. In this way as well as in other leading and original activity, Professor de Broglie, notably in the evolution of undulatory mechanics, has been an indefatigable investigator. Not many months ago his erudite Mecanique Undulatoire made its appearance, and now he amplifies the subject in the present work.

In great part, the subject matter is a reproduction of the course conducted by the author at the Institut Henri Poincare, of the Faculte des Sciences of Paris during the first semester 1929–1930. Presupposing no acquaintance on the part of the reader with his previous works, he reviews in a first part, which occupies about one-third of the volume, the general principles of the new mechanics. This first part is accordingly an introduction, and the subject proper is entered upon in its second part. Here, after a few chapters dealing with indispensable mathematical preliminaries, is developed the general theory by which may be determined the quantified values of material magnitude and the respective probabilities of these quantified values. The author points out in his conclusion the original character, entirely opposed to classical notions of the conception which the new mechanics makes of quantified states and their superposition. Even those imbued with the old fundamentals who will find this new conception quite strange, he further remarks, must recognize its logical derivation from the existing state of our knowledge of physics and that its evolution follows from it in a precise and coherent form.

L. E. P.

Fixed Nitrogen, edited by Harry A. Curtis. Contributors: F. E. Allison, Harry A. Curtis, J. R. Dilley, W. L. Edwards, P. H. Emmett, E. W. Guernsey, P. E. Howard, H. J. Krase, N. W. Krase, C. H. Kunsman, Albert R. Merz, William H. Ross, Richard Wiebe. American Chemical Society Monograph Series. 517 pages, tables, illustrations. 15.5 × 23.5 cms. New York, The Chemical Catalog Company, Inc., 1932. Price $12.00.

This book might well be considered a milestone in the progressive development of nitrogen fixation. In it will be found a total of sixteen chapters, each covering some particular and important phase of the subject; each written by a person or persons thoroughly informed upon such topics. As the editor, H. A. Curtis, points out, the monograph is, in a way, a product of the Fixed Nitrogen Research Laboratory in that all the authors are, or were sometime in the past, members of the Laboratory research staff.

Presentation of the subject matter is done in what might be termed the most approved manner. The book begins with a general survey of the sources and utilization of fixed nitrogen. Natural fixation methods are discussed and followed by expositions on the two great natural sources of fixed nitrogen, nitrate deposits and products of coal carbonization. There are two outstanding direct methods for fixing nitrogen. One is to combine the element with oxygen to give nitrogen oxides; the other involves a combination with hydrogen to give ammonia.

This latter process has supplanted all the others in respect to its industrial importance.

Following a brief chapter on the history of nitrogen fixation processes which, in addition to the two just mentioned, includes the cyanamide and alkali cyanide methods as well, further preliminary information is furnished in the chapter on physical methods of studying chemically active states of gases and of investigating catalyst surfaces. Complementary to the articles on the "Arc Method of Nitrogen Fixation" and "Synthetic Ammonia" are valuable data on some physical properties of hydrogen, nitrogen, methane, ammonia, carbon monoxide and carbon dioxide and their mixtures. Coincident with this last chapter is another of equal importance on high pressure equipment and technic.

Leaving behind the briefer chapters covering the cyanamide, alkali cyanide and synthesis of urea methods, we again come to one of relative great importance, that on the oxidation of ammonia. In the production of nitrates, ammonia oxidation is as an essential a step as the synthesis of the ammonia itself. Considerable quantities of research have been accorded this oxidative process and much valuable information and data are furnished in the chapter.

Very appropriately, a chapter on synthetic nitrogenous fertilizers has been included. Some idea as to its extent may be had by realizing that a fertilizer may contain one or more of the calcium, potassium, sodium or ammonium salts of carbonates, phosphates, nitrates, sulfates and even chlorides, not to mention a number of simple and complex organic nitrogen compounds. What a large number of problems are involved in preparing combinations that will not cake or absorb moisture excessively; will be suitable for a particular soil or crop; will be economically sound in its application. The photograph of the interior of a spray tower, p. 453, is a classic in its field.

To top off these five hundred pages of fixed information and data, an extensive series of nitrogen statistics is appended. Glancing over these tables it was interesting to see that there now exists in Germany a synthetic ammonia plant capable of fixing 600,000 net tons of nitrogen per year. Following the statistics comes an equally imposing bibliography containing seven hundred seventy-eight references.

Fixed Nitrogen is well and interestingly written. The subject has been treated with a high degree of completeness at the same time presented in a clear and simple manner. The book should prove a handy reference to the instructor, the student, the industrial chemist as well as a treatise of general interest to others.

T. K. CLEVELAND.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS:

Report No. 416, The N. A. C. A. Variable-Density Wind Tunnel, by Eastman N. Jacobs and Ira H. Abbott, 12 pages, illustrations, 23 × 29 cms. Washington, Superintendent of Documents, 1932. Price five cents.

This report describes the redesigned variable-density wind tunnel of the National Advisory Committee for Aeronautics; it supersedes a previous report that described the original tunnel. The operation of the balance and the method of testing are explained and the method of correcting and presenting airfoil data is described. A summary of the formulas for predicting the characteristics of finite wings from the airfoil section data as they are usually presented is also given.

Report No. 421, Measurement of the Differential and Total Thrust and Torque of Six Full-Scale Adjustable-Pitch Propellers, by George W. Stickle, 22 pages, illustrations, 23 × 29 cms. Washington, Superintendent of Documents, 1932, price ten cents.

Force measurements giving total thrust and torque, and propeller slipstream surveys giving differential thrust and torque were simultaneously made on each of six full-scale propellers in the 20-foot propeller-research tunnel of the National Advisory Committee for Aeronautics. They were adjustable-pitch metal propellers 9.5 feet in diameter; three had modified Clark Y blade sections and three had modified R.A.F. 6 blade sections. This report gives the differential thrust and torque and the variation caused by changing the propeller tip speed, V/nD, and the pitch setting. The total thrust and torque obtained from integration of the thrust and torque distribution curves are compared with those obtained by direct force measurements.

In the above comparison the torques measured by the two methods were directly comparable but the thrusts derived from the slipstream survey differed from those obtained from the force measurements by two factors, the drag of the hub and the increase of body drag due to the slipstream. Since single values of two coefficients used to obtain the factors brought all the thrust curves measured by the two methods into very good agreement, it is believed that the factors represent accurately the drag of the hub and the increase of body drag due to the slipstream.

Report No. 424, Wind-Tunnel Research Comparing Lateral Control Devices, Particularly at High Angles of Attack. IV. Floating Tip Ailerons on Rectangular Wings, by Fred E. Weick and Thomas A. Harris, 25 pages, illustrations, 23 × 29 cms. Washington, Superintendent of Documents, 1932, price ten cents.

This report is the fourth of a series on systematic tests conducted by the National Advisory Committee for Aeronautics, which compare lateral control devices with particular reference to their effectiveness at high angles of attack. The present report covers tests with floating tip ailerons on rectangular Clark Y wings. Ailerons of two profiles were tested—symmetrical and Clark Y, both with adjustable trailing-edge flaps. Each form was tested at three hinge-axis locations, both with and without vertical end plates between the ailerons and the wing proper. The results from these tests are compared with the results from tests on a wing of the same over-all size equipped with average-sized ordinary ailerons.

All the wing-tip floating ailerons tested had about the same characteristics throughout except for their effect on the general performance of the wing. The general performance was found to be definitely poorer for all of the rectangular wings with floating tip ailerons than with a wing having the same over-all dimensions and ordinary ailerons. At the stall and just above, the rolling control was less than an assumed satisfactory value, but was appreciably better than with the standard wing with ordinary ailerons. At angles of attack above 22° the control with the wing-tip ailerons was found to be greater than the assumed satisfactory value, whereas the ordinary ailerons on the standard wing failed almost com-

pletely. The wings with floating tip ailerons gave no appreciable adverse yawing moments (body axis), but gave large favorable ones at high angles of attack. The instability in rolling was not as bad as for the wing with ordinary ailerons.

Report No. 427, The Effect of Multiple Fixed Slots and a Trailing-Edge Flap on the Lift and Drag of a Clark Y Airfoil, by Fred E. Weick and Joseph A. Shortal, 8 pages, illustrations, 23 × 29 cms. Washington, Superintendent of Documents, 1932.

Lift and drag tests were made on a Clark Y wing equipped with four fixed slots and a trailing-edge flap in the 5-foot vertical wind tunnel of the National Advisory Committee for Aeronautics. All possible combinations of the four slots were tested with the flap neutral and the most promising combinations were tested with the flap down 45°. Considering both the maximum lift coefficient and the speed-range ratio $C_{L\max.}/C_{D\min.}$, with the flap neutral no appreciable improvement was found with the use of more than the single leading-edge slot. With the flap down 45° a maximum lift coefficient of 2.60 was obtained but the particular slot combination used had a rather large minimum drag coefficient with the flap neutral. With the flap down 45° the optimum combination, considering both the maximum lift coefficient and the speed-range ratio, was obtained with only the two rearmost slots in use. For this arrangement the maximum lift coefficient was 2.44.

Report No. 428, Wind-Tunnel Tests of a Clark Y Wing with a Narrow Auxiliary Airfoil in Different Positions, by Fred E. Weick and Millard J. Bamber, 14 pages, illustrations, 23 × 29 cms. Washington, Superintendent of Documents, 1932, price ten cents.

Aerodynamic force tests were made on a combination of a Clark Y wing and a narrow auxiliary airfoil to find the best location of the auxiliary airfoil with respect to the main wing. The auxiliary was a highly cambered airfoil of medium thickness having a chord 14.5 per cent. that of the main wing. It was tested in 141 different positions ahead of, above, and behind the nose portion of the main wing, the range of the test points being extended until the best aerodynamic conditions were covered.

A range of positions was found in which the combination of main wing and auxiliary gave substantially greater aerodynamic efficiency and higher maximum lift coefficients (based on total area) than the main Clark Y wing alone. In the optimum position tested, considering both the maximum lift and the speed-range ratio, the combination of main wing and auxiliary gave an increase in the maximum lift coefficient of 32 per cent. together with an increase in the ratio $C_{L\max.}/C_{D\min.}$ of 21 per cent. of the respective values for the main Clark Y wing alone.

HOW TO MAKE GOOD PICTURES, a book for the amateur photographer. Anonymous. xii–185 pages, illustrations, 13 x 19.5 cms., half cloth, seventeenth edition, revised. Rochester, Eastman Kodak Company. Price fifty cents.

Forty and some odd years ago an ingenious and enterprising manufacturer of cameras brought out a simplified hand-camera adapted to the use of the then

newly invented roll film. The capacity of the film was one hundred exposures, the intention being to do the finishing at the factory or service station and so relieve the user of all effort in the production of the pictures except making the exposures. This camera was called "Kodak," a name with no etymological significance, but one which is easily pronounced and easily remembered, and by the quality of the product which it represents has become a symbol of dependable photographic material and service. Among the many ways in which the famous company which manufactures the Kodak announces its products, not the least has been the liberally distributed supply of valuable photographic information of interest to both professional and amateur which it has continuously disseminated over a long term of years.

The present handbook is a comprehensive guide which covers the needs both of beginners and advanced workers. Divested of all academic discussion of the technics of the subject, it dwells upon what can be done with the camera, and how it must be done to insure satisfactory results. Among the innumerable topics that enter into the process of making a picture is the critical matter of determining the time of exposure. To that end a set of representative subjects is illustrated each inscribed with the proper timing for guiding the photographer in choosing the proper setting of the shutter. In the absence of the recent photoelectric and photometric exposure meters there is probably no more practical way of determining exposure. Besides the collection of information within the volume on every phase of picture making, there is a supplement which describes the new verichrome film and the photoflash and photoflood lamps. The last is a low-voltage 60-watt lamp which, connected to the usual 115-volt circuits, yields a light equivalent to a 750 to 1000-watt general service lamp, of course with the very much shortened life of two hours of continuous burning, but that is long enough for many exposures in careful hands.

How to Make Good Pictures is no newcomer, for we are told over a million copies have already been sold. That indeed may be the reason why so many vacationists now bring home pictures of professional quality.

LUCIEN E. PICOLET.

PUBLICATIONS RECEIVED.

Applied Colloid Chemistry, General Theory, by Wilder D. Bancroft, third edition, 544 pages, tables, 15 x 21 cms. New York and London, McGraw-Hill Book Company, Inc., 1932.

Modern Physics, a second course in college physics, by G. E. M. Jauncey, 568 pages, illustrations, tables, 14.5 x 22.5 cms. New York, D. Van Nostrand Company, Inc., 1932. Price $4.00.

Recent Advances in Atomic Physics, by Gaetano Castelfranchi, approved translation by W. S. Stiles and J. W. T. Walsh, 2 volumes, illustrations, tables, 13.5 x 25 cms. Philadelphia, P. Blakiston's Son & Co., Inc., 1932. Price $4.00 each.

University of Chicago, Yerkes Observatory, Publications, Volume VII, Part II, A Study of the Spectrum of 7ε Aurigæ, by Edwin B. Frost, Otto Struve, and C. T. Elvey, 52 pages, plates, tables, illustrations, 23.5 x 30 cms. Chicago, University of Chicago Press. Price $1.50.

Vowel Positions as Shown by X-ray, by C. E. Parmenter and S. N. Trevino, 18 pages, illustrations, 16.5 x 24.5 cms. Reprinted from the Quarterly Journal of Speech, June 1932.

Ontario Department of Mines, Forty-first Annual Report, vol. XLI, part II, 1932, 67 pages, illustrations, maps, tables, 16.5 x 24.5 cms. Toronto, King's Printer, 1932. Bulletin No. 83, Twenty-Five Years of Ontario's Mining History, 55 pages, tables, maps, 16.5 x 24.5 cms. Toronto, King's Printer, 1932.

Bell Telephone Laboratories, Monographs: B-675, The Principles of the Light Valve, by T. E. Shea, W. Herriott, and W. R. Goehner, 34 pages, illustrations, 15 x 23 cms. B-676, Plane Waves of Light—III, by Thornton C. Fry, 26 pages, tables, illustrations, 15 x 23 cms. B-677, Sound Diffraction by Rigid Circular Plate, Square Plate and Semi-Infinite Screen, by L. J. Sivian and H. T. O'Neil, 28 pages, diagrams, 15 x 23 cms. B-678, A Method of Measuring Acoustic Impedance, by P. B. Flanders, 9 pages, diagrams, 15 x 23 cms. B-679, An Efficient Miniature Condenser Microphone System, by H. C. Harrison, and P. B. Flanders, 11 pages, diagrams, 15 x 23 cms. B-680, Wire Communication Aids to Air Transportation, by H. H. Nance, 15 pages, illustrations, 15 x 23 cms. B-681, Cæsium-Oxygen-Silver Photoelectric Cell, by C. H. Prescott, Jr., and M. J. Kelly, 34 pages, illustrations, 15 x 23 cms. B-682, Magnet Steels and Permanent Magnets, by K. L. Scott, 21 pages, diagrams, 15 x 23 cms. B-683, Transmission Lines for Short-Wave Radio Systems, by E. J. Sterba and C. B. Feldman, 40 pages, illustrations, 15 x 23 cms. B-684, Two-Way Radio Telephone Circuits, by S. B. Wright and D. Mitchell, 15 pages, diagrams, 15 x 23 cms. B-685, The Depth of Origin of Photoelectrons, by Herbert E. Ives, and H. B. Briggs, 11 pages, diagrams, 15 x 23 cms. B-686, The Transmission and Reflection of Wave Packets by Potential Barriers, by L. A. MacColl, 6 pages, diagrams, 15 x 23 cms. B-687, Dielectric Properties of Some Glycols, by A. H. White and S. O. Morgan, 8 pages, diagrams, 15 x 23 cms. B-688, Kennelly-Heaviside Layer Studies Employing a Rapid Method of Virtual-Height Determination, by J. P. Schafer and W. M. Goodall, 18 pages, diagrams, 15 x 23 cms. New York, 1932.

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lurgical Works in the United States, during the Calendar Year 1930, by William W. Adams, 36 pages, tables, 15 x 23 cms. Washington, Government Printing Office, 1932.

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CURRENT TOPICS.

Frozen Fish—Doing It Right.—(*Ind. and Eng. Chem.*, **24**, 679.) At first thought one would not suspect the problem of preserving fish by freezing would differ essentially from that for other meats such as beef, pork, lamb and so forth. However, it must be borne in mind that fish are cold-blooded and their body temperature is usually within 1° C. of the temperature of the water in which they live. Although fish have the advantage of not having to catch, digest, and metabolize large amounts of food to keep their bodies warm, they, on the other hand do not enjoy the advantage of favorable temperatures for enzymic reactions of digestion and other physiological processes. Halibut is found in water from 32° to 39° F., cod from 35° to 45° F. and haddock from 39° to 50° F. In order that a fish may digest its food at 32° F. it must possess enzymes particularly effective at such a low temperature. The digestive enzymes, therefore, are extraordinarily potent and if not quickly suppressed will do great and rapid damage after death. Fish also contain a relatively powerful autocatalytic enzyme which enables it to digest its tissues at times when food is scarce or it is so cold the movements are sluggish and food cannot be gathered in. The presence of such enzymes, active at the freezing point of water, will account for the failure of fish to keep satisfactorily at those temperatures found to be quite suitable for flesh of warm-blooded animals.

As might be expected, refrigeration, carried to the extent of hard-freezing and storage under protection of impervious containers at low and constant temperature, is the most perfect known preservative for fish in arresting all the changes mentioned. The latest and most advanced methods for so preserving fish on a commercial scale are adequately described by H. F. Taylor.

As soon as the fish arrive on the deck of the boat, they are eviscerated, washed under strong sprays of clean sea water, then carefully sent to the hold where they are stowed in finely crushed ice on shallow shelves. At the packing house, the fish are skillfully cut into boneless fillets, the skin still attached. A novel machine has just recently been developed for the purpose of separating the skin from the flesh. A flexible metal belt passes around two hollow cylinders, one at a temperature of 68° F., the other at − 11° F. The fillet is laid skin down upon the belt and as it passes over the

cold cylinder, the skin becomes firmly frozen to the metal band. A rapidly oscillating knife (about 1000 strokes per minute) now separates the flesh from the skin, which later drops from the belt as it passes over the warm cylinder. After a special cooling the fillets pass to a machine that overlaps and compresses them into the form of a cylinder which is rapidly wound with a tape of pure vegetable parchment. This taped cylinder is about 3½ inches in diameter and is cut by a rapidly revolving knife into slices ¾ inch thick. These slices or steaks are now laid in shallow pans having integrally cast ribs or vanes projecting from the underside. These ribs dip into the freezing solution of brine as the pans skim its surface and the heat is slowly extracted from the fish steaks. Once frozen, only the packaging operation remains. The packages are carefully constructed, are enclosed in moisture-proof cellophane and stored in refrigerated spaces awaiting ultimate consumption.

C.

Remedies For Headaches.—DR. F. J. CULLEN, Chief of drug control, Federal Food and Drug Administration, issues a timely warning to persons who carelessly use headache powders, tablets, medicines, or certain other temporary reliefs for pain. "Acetanilid, acetphenitidin, amidopyrine, aspirin and other coal-tar derivatives, are commonly found in headache powders and pills," says Dr. Cullen. There is a possibility that any one of these coal-tar derivatives will have a depressing effect on the heart of certain individuals who are particularly susceptible.

A recently reported fatality from taking an overdose of acetanilid—four times the prescribed amount—lends emphasis to this warning. The Federal Food and Drugs Act cannot prohibit the sale of such drugs, valuable in moderation and dangerous in excess. However, the act does demand that their poisonous properties be stated upon the labels that the purchaser may read and take heed.

C.

Pipe Spinning.—(*Chem. & Ind.*, **51**, 648.) This year the members of the Society of Chemical Industry held their Annual General Meeting at Nottingham. As is the case with all such well-conducted get-togethers, the participants refused to place complete reliance in their auditory equipment and at convenient intervals between papers and speeches took sightseeing trips to a number of local plants where, after viewing many interesting industrial processes, they realized that after all "Seeing is believing."

A visit of general interest was that to a plant engaged in the spinning of concrete and iron pipes. The former kind is made by

the so-called Hume process which was demonstrated to the visitors through the fabrication of a 60-inch diameter reinforced concrete pipe. The mold with the reinforcement inside was mounted horizontally on a machine which revolved it rapidly. Beginning inside at one end of the mold, concrete was deposited against the walls by means of the centrifugal forces due to the mold's rapid revolution. Thus the pipe is formed by the winding of a spiral ribbon of plastic concrete from one end of the mold to the other. After spinning, the molds are deposited in a steaming chamber for curing. Upon completion of this phase, the molds are removed and the pipes taken to the stock yards where they are subjected to a water-spray treatment.

The iron pipe is spun by what is known as the De Lavand system. An interesting fact is that iron direct from the blast furnace is not used for forming the pipes. The reason is that iron for spinning pipe must have a definite composition and so must be analysed before using. An iron with a silicon content of about 2.6 per cent. is considered to be most suitable. Since iron from the blast furnace cannot guarantee this exact silicon content, remelting is necessary.

The pipe is formed in an accurately machined cylindrical steel mold which is revolved on its own axis by means of an impulse water turbine inside a water-cooled iron casing. The molten iron is fed to the mold by means of a tilting ladle and a cantilever trough. When ready to pour, the revolving mold is brought to the correct speed and moved toward the ladle so that the cantilever trough extends inside the mold to the more distant socket end. The ladle is now tilted and the molten iron discharges into the interior of the mold where centrifugal forces press it against the walls. As the metal flows the mold recedes at a uniform speed until an iron pipe has been spun the full length of the mold. The rate of tilting of the ladle, the peripheral speed of the mold and the traverse of the machine all are in a constant ratio for any particular size and thickness of pipe. The iron solidifies in a few seconds and when contraction has taken place the pipe is withdrawn. It passes directly to an annealing furnace where its temperature is slowly raised to about 1700° F. In the latter portion of the furnace the pipe cools down so as to prevent sudden chilling upon emerging. A deflection test was made on a 4-in. diameter iron pipe about 12 ft. long. The pipe was supported at both ends in a horizontal position and the load applied at the centre. It withstood a weight of over 4 tons before breaking and showed a deflection of about 5½ in.

C.

Pigment of Yellow Wool.—Lanaurin, the golden pigment of the wool of certain sheep, has been studied by CLAUDE RIMINGTON AND A. M. STEWART (*Proc. Royal Soc.*, London, 1932, *B 110*, 75–91). They find that lanaurin apparently is a pyrrole complex, intermediate between the bile pigments and fully condensed melanin. It is produced from the hemoglobin of the blood by an inherited hyperactivity of certain cells, which are known collectively as the reticuloendothelial system, is secreted in the perspiration, and dyes the wool.

J. S. H.

Damming the Dnieper.—(*Engineering News-Record*, *108*, 877.) The Dnieprostroy hydro-electric and navigation project is located in the republic of Ukraine in south-central Russia, at a point on the Dnieper river near Kichkas, about 200 miles above where the river discharges into the Black Sea. Although the river is navigable both above and below the point chosen for the power site, a stretch of rapids at this location necessitates the construction of locks. According to a 46-year record the rivers flow ranges from 6,300 to 720,000 sec.-ft. In the great flood of 1931 the flow amounted to 835,000 sec.-ft.

In deciding the generating capacity that should be installed, consideration was taken of the flow, the probable load factor which ultimately would develop in this territory; the cost of steam power and the unit cost of the hydro-electric installation; the fact that the storage capacity of the reservoir behind the dam amounted to 39,000,000,000 cu. ft. for a 20-ft. drawdown; and, that the major part of available power would be used for the production and manufacture of ferrous and non-ferrous metals in the vicinity of the power site. As a result, an installation of nine units, each of 84,000 hp rated capacity at average head, a total of 756,000 hp, was decided upon.

The main dam extending entirely across the river channel is 140 ft. high to the crest of the spillway and almost 200 ft. to the top of the piers. The spillway has been designed for an overflow depth of 30 ft. The total length of the dam is 2,500 ft. and has a radius of curvature of 1968.5 ft. The method of construction was similar to that found successful in this country. It consisted in first building a row of piers across the river, then closing off the openings between the piers during periods of low water. These piers, in addition to taking the thrust of the crest gates, support a track for the gate-operating cranes and a highway bridge.

On the left bank are three navigation locks having lifts of 41 ft. each. On the right side of the river, the power-house bulkhead,

850 ft. long, forms a continuation of the dam into the right bank. The power-house generating units are the largest in physical size and capacity ever built. The water wheels will develop more than 100,000 hp under a maximum head of 123 ft. operating at 88.2 r.p.m. Each runner weighs 160 tons and is 19 ft. 10½ in. at its largest diameter. Directly connected to each water wheel will be a 13,800-volt three-phase, 50-cycle generator having a continuous rated capacity of 77,500 kva at 0.8 power factor and 60° C. temperature rise. The framing of the generator is of welded steel construction with the thrust bearing mounted above. This bearing is of the spring type and designed to support a load of 2,000,000 lbs. which is the total weight of the generator rotor, the 41-in. diameter, 58-ft.-long shaft, the water wheel and the reaction of the water.

Provision has been made to prevent heavy ice accumulations around the crest gates on the dam by installing compressed air outlets along the crest of the dam.

C.

Nailable Cinder Blocks.—(*Engineering News-Record, 108*, 903.) A nailable cinder block for building work is described. This new block is made of asbestos fiber in combination with cement, sand and cinders and is a nailable fireproof unit. It is steam-treated instead of burned and retains its shape as molded. It is claimed the blocks will transmit less heat than the ordinary plain cinder blocks and that with the asbestos content, sound transmission through the walls and floors is largely eliminated.

C.

German Exhibition.—Direct from Seelze, near Hannover, Germany, comes a notice black-printed on a sheet of paper predominantly reflecting light rays of the length of 6550 Å or thereabouts. Pausing to read such an attention-commanding notice one finds there is to be a German Chemical Plant Exhibition at Cologne around the first part of June, 1933. This exhibition is to be held coincidently with meetings of the German Chemical Society, Society of German Rubber Chemists, the Association of German Fuel Technologists as well as other scientific and technical societies.

C.

Silica Black.—At the Fall Meeting of the American Chemical Society held in Denver, Col., C. A. Jacobson submitted an interesting account of the manufacture of Silica Black. Apart from its rock-crystal form one is most accustomed to seeing silica in the state of a white sand or very fine powder existing in a natural state

under the name of kieselguhr or diatomaceous earth. In the preparation of Silica Black, finely divided coal is intimately mixed with a siliceous material such as diatomaceous earth, and the mixture heated in the absence of air to between 1,000 and 1,200 degrees. The resulting powder is air floated and separated into three grades, the finest having a gravity of 0.25 and composed of about 18 per cent. carbon, 74 per cent. silica, and 8 per cent. oxides, sulfides, silicides of iron, aluminum, etc.

Silica Black has a high oil absorption, mixes well, and has good spreading quality. It therefore might be used as a pigment in paints, printing inks, etc. It reduces metallic oxides at high temperatures. It adheres tenaciously to objects and might be used as a carrier for insecticides, in wood graining, leather tinting, etc. It might be used as a support for nickel in various hydrogenation processes. It is probable that smoke belching from stacks is largely Silica Black.

C.

Oligo-Dynamic Action of Metals.—Readers interested in water purification are familiar with the term "oligo-dynamic." It describes an effect "produced by a relatively small force." It is known that preparations of finely divided metals such as silver or copper very effectively remove harmful microörganisms from water. Apparently the specific action of these metals is not due to the formation of a metallic ion which, if the case, would be catalogued as a chemical reaction. To classify the action of the metal as purely mechanical might raise a question of terminology so, after all, "oligo-dynamic" may well be accepted as an appropriate and exclusive name for a metal's retarding influence upon the activity of certain living organisms.

At the present time, the oligo-dynamic properties of silver are receiving particular attention in a practical way. Now H. LANGWELL (*Chem. & Ind.*, *51*, 701) reports a series of observations made by him upon the oligo-dynamic action of metallic iron. Mention is made of a case where iron had a strongly inhibiting action on an actively fermenting culture of thermophilic (more aided than hindered by heat) cellulose-fermenting organisms. Iron compounds such as hydroxides, sulfides, etc. permit the fermentation to proceed normally. A striking demonstration of the reality of the oligo-dynamic activity of a clean iron surface was furnished by a 2,000-gallon wooden tank containing 30–40 ft. of 1-in. iron pipe. So long as the culture was not stirred, fermentation proceeded with such vigor that the fermenting cellulose with its entrained gas rose and formed the typical "cap" over the culture liquid. At this stage

stirring became necessary in order to neutralize the acid rapidly accumulating in the "cap," otherwise fermentation would have been inhibited by the rise in acidity. A few hour's gentle stirring markedly retarded fermentation and in less than twelve hours fermentation was almost completely arrested. This retardation did not occur in wooden or aluminum fermenters from which metallic iron was excluded. In these cases stirring tended rather to accelerate fermentation. Samples of such inactivated culture from the iron-containing fermenter taken during a period of stirring and placed in glass flasks in an incubator, rapidly commenced normal fermentation.

An interesting feature of this phenomenon is that the fermenting bacteria remain alive as evidenced by the return of the fermentation when placed in a glass vessel. It is Langwell's supposition that the oligo-dynamic properties of the iron may inactivate in some way the enzymes of fermentation which are present in the liquid and external to the uni-celled bacteria. Oligo-dynamic action may therefore be expected to interfere with enzyme activity without injuring the organism, in contrast with the action of toluene which injures the organism without interfering with enzyme activity.

C.

Better Book Covers.—*Chemistry and Industry* for August 19, 1932 has an interesting article on book covers. It points out that not so many years ago leather was considered the only suitable material for binding books of permanent interest. Now in this day of books for everybody, quality and measured care must give way to speedy output and the more reasonably price cloth bindings.

Generally speaking, bookbinding fabrics consist of cotton or linen cloths which have been given solidity and finish by the use of various filling materials, starches, gums, earths, etc. colored by pigments and dyestuffs. Most of these colors are susceptible to light and it is more often the rule than the exception to find that the spines of books, stacked in a case in the conventional manner, have become several shades lighter than the better protected sides. Then again, many of the fillers and the dyes, in particular, are prone to rub off on the slightest provocation, such as when touched by moistened fingers. Everybody recalls the delapidated appearance of a clothbound book after having spilled upon it water or drinks of a more exhilarating nature. (We remember how the dark green covers of our school readers would develop almost white and turgid spots where rain or melted snow had come in contact.)

Book lovers may look forward to a time not far remote when many of the books will bear bindings of a superior quality. *Chem-*

istry and Industry states that a well-known English firm has now produced a series of bookcloths which are fast to light, undamaged by water and, in fact, can be washed if accidently soiled. These bookcloths may be had in a variety of colors from some of the fastest dyestuffs known. Particularly attractive are those bindings of Caledon Jade Green, the fastest green dye in existence. The one and only G. B. S. has chosen very appropriately this permanent and ever fresh Caledon Jade Green to enclose a 30-odd volume edition of his works. A later edition has been bound in the unique Venetian Sail-cloth Red, probably a complementary color.

C.

Pot-Pourri.—(*The White Metal News Letter.*) Maybe the housewife's complaint that kneading dough tires her arms is thoroughly justified. Dough is so resistant that it bends cast steel paddles a foot long and an inch thick at the neck and which do the kneading job for the mixing machines. In order to make these paddles stand up under this severe service, nickel alloy steel has been specified for them. Incidentally, it requires no less than eight horse power to push one of these paddles through dough at the rate of 12 times a minute. Bread requiring the consumption of that much energy should be good.

And now we have oyster shoes which permit oyster fishermen to walk over oyster beds without sinking very much in the manner that snowshoes hold a person on top of the snow. In the State of Washington there is being cultivated a small-sized bivalve alliteratively called the Olympia oyster. That they will not be trampled deep into their beds, the gatherers wear these special shoes consisting of monel metal channels and wires set in a wooden frame and having a device for attaching to the rubber boots of the wearers.

A cap of nickel-chromium stainless steel will gleam from the summit of the 60-foot monument to be built in the Arctic wastes as a memorial to Admiral Robert E. Peary, discoverer of the North Pole. This monument will stand on a high Greenland plateau overlooking Cape York about 600 miles inside the Arctic Circle.

From torpedoes to bananas reads the fate of two former U. S. torpedo boat destroyers. With all naval accoutrements removed and the steam power plants replaced by Diesel engines, the speedy, broad-beamed, shallow-draft hulks are particularly suited for the transportation of perishable fruit.

Before purchasing objects of white gold it might be well to make careful inquiries as to its caratage. There is a 12-carat white gold containing 20 per cent. nickel, 20 per cent. copper and 10 per cent. zinc. An 18-carat white gold contains nickel, zinc and copper in

percentages of 16.5, 5.0 and 3.5 respectively. Then again there is a truly noble white gold—21.6 carat—consisting of 90 per cent. gold and 10 per cent. palladium.

The development of light and strong aluminum alloys for automobiles and aeroplanes goes on apace. Certain new alloys differ from older strong alloys in that a minimum of copper is used, a mixture of nickel and chromium being alloyed with the aluminum instead. This alloy has been fabricated in the form of extruded sections which, with structural sections, have been made with 60,000 pounds yield point and 70,000 pounds ultimate strength. They give a 15 per cent. elongation and have an elasticity indicated by 3-T, which means that a sheet can be bent over a radius of two to three times the thickness of the sheet.

The average length of use of a truck motor valve is about 15,000 miles before regrinding is necessary. In order to lower replacement costs, several large bus operators have begun tests on a valve which has a monel metal stem and copper-nickel head. It is said to last several times as long as the ordinary valve.

Instead of the yellow gold leaf, the booklover may have his much prized volumes titled in white palladium leaf.

Pure nickel rod, one-half-inch round, is being used to administer radium treatments in the Henry Ford Hospital, Detroit. The radium is placed in a shallow cup machined in one end of the rod and allowed to filter through the metal during the treatment.

C.

Tooth Paste Myths.—(U. S. Department of Agriculture Clip Sheet No. 138.) While some tooth pastes and dentifrices are advertised as cures or preventives for pyorrhea, Riggs' disease, tender gums or other mouth disorders, the buyer will find very few, if any, dentifrices entering into interstate trade actually labeled with remedial claims for these maladies.

According to Dr. F. J. CULLEN, of the Federal Food and Drug Administration, there is no drug nor combination of drugs capable of curing pyorrhea and certain other diseases of the mouth. Nor may the buyer expect to find any tooth paste which has any permanent effect in correcting tooth decay and what is popularly known as halitosis.

Dentifrices have no magical composition, says Cullen. Their ingredients include precipitated chalk, soap, water, baking soda, borax, magnesia, glycerin, alcohol, a sweetening agent and medicinal oils intended to give the article an attractive color or taste.

C.

Oil of Japanese Peppermint.—B. V. CHRISTENSEN AND LOVELL D. HINER (*Jour. Am. Pharm. Asso.*, 1932, XXI, 793–795) have analyzed the essential oil of Japanese peppermint (*Mentha arvensis* var. *piperescens*) obtained from two strains of that plant grown in Florida during four successive years. The menthol content of the oil was somewhat low, the average values on the two strains being 67 per cent. and 71 per cent., respectively. The menthol content was fairly uniform from year to year. The per cent. of the total menthol present as esters was relatively low. However, the plants, apparently, do not adapt themselves well to the hot climate of Florida.

J. S. H.

Methionine Content of Proteins.—Methionine is alpha amino gamma methylthiol normal butyric acid. It was discovered in the proteins in 1921, and is one of the comparatively few sulphur-containing segments of the protein molecule. HARRY D. BAERNSTEIN (*Jour. Biol. Chem.*, 1932, XCVII, 663–668) has determined the methionine content of 37 proteins; the lowest value obtained was 0.54 per cent. in the peanut protein arachin, the highest value 5.29 per cent. in albumin.

In a second paper, BAERNSTEIN (*Jour. Biol. Chem.*, 1932, XCVII, 669–674) reports a study of the partition of the sulphur in 32 purified proteins, with special reference to methionine and the sulphydryl-disulphide (cysteine-cystine) sulphur. Expressed as per cent. of the total sulphur of the protein, the methionine sulphur ranged between 26.0 and 90.0 per cent., while the sulphydryl-disulphide sulphur ranged between 17.7 and 84.3 per cent.

J. S. H.

Occurrence of Caffeine in Cereal Beverages.—CHARLES H. LA WALL AND JOSEPH W. E. HARRISSON (*Am. Jour. Pharm.*, 1932, CIV, 537–539) report the addition of either caffeine or the infusion or extract of some caffeine-containing plant to cereal beverages in order to impart the stimulating action of that purine alkaloid to the product. The presence of caffeine, however, is not declared on the label. Twenty different brands of cereal beverages were examined; in five of these brands, caffeine was present; its concentration was approximately one-half grain to each bottle.

J. S. H.

Quince Seed Mucilage.—ALICE G. RENFREW AND LEONARD H. CRETCHER (*Jour. Biol. Chem.*, 1932, XCVII, 503–510) have hydrolyzed quince seed gum and obtained a cellulosic fraction, a mixture

of methylated and unmethylated aldobionic acids, and the aldopentose arabinose. On further hydrolysis of the aldobionic acids, another pentose, xylose, was obtained.

J. S. H.

Biochemical Aspect of Evolution.—DOROTHY MOYLE NEEDHAM, JOSEPH NEEDHAM, ERNEST BALDWIN, AND JOHN YUDKIN (*Proc. Royal Soc.*, London, 1932, *B*, CX, 260–294) have made a systematic survey of the phosphagens of invertebrates, with special reference to the occurrence of arginine phosphate (the characteristic phosphagen of invertebrates) and creatine phosphate (the characteristic phosphagen of vertebrates). Creatine phosphate was identified by five different methods, and found present in *Strongylocentrotus* (an echinoderm) and in *Balanoglossus* (an enteropneust). The conclusion is drawn that vertebrate descent occurred through these two species.

J. S. H.

New Test for Magnesium.—C. FRANKLIN MILLER (*Chemist-Analyst*, 1932; XXI, No. 5; 6–7) recommends, as a reagent for the detection of the presence of magnesium, the azo dye which is obtained by the reaction between diazotized benzidine and the sodium salt of resorcinol. The dark brown dye is used as its sodium salt, in 0.05 per cent. aqueous solution. The solution, which is to be tested for the presence of magnesium, is made slightly acid with hydrochloric acid; 10 drops of the dye solution are added, then sufficient 10 per cent. solution of sodium hydroxide to make the solution alkaline. A deep blue color lake precipitates if magnesium be present. The reaction is not given by bismuth, zinc, aluminium, barium, strontium, and calcium. However, calcium yields a reddish precipitate if its ions be present in sufficient concentration to exceed that of calcium hydroxide. Cadmium forms a light blue lake. Similar lakes are formed by a number of azo dyes containing the resorcinol residue.

J. S. H.

Halibut Liver Oil.—H. D. EMMET, O. D. BIRD, C. NIELSEN, AND H. J. CANNON (*Ind. Eng. Chem.*, 1932, XXIV, 1073–1077) report that halibut liver oil is the richest known natural source of vitamins A and D. With respect to vitamin A, it is from 75 to 125 times as potent as cod liver oil. With respect to vitamin D, which protects from rickets, it is from 15 to 20 times as potent as cod liver oil. Halibut liver oil is readily tolerated, even in massive doses, and may be ingested with impunity.

J. S. H.

James Woodhouse and the Synthesis of Ammonia.—JAMES WOODHOUSE (1770–1809) was a graduate of the University of Pennsylvania in both arts (1787) and medicine (1792). He was elected professor of chemistry in the medical school of the University, when Joseph Priestley declined that honor in 1795, and served until his death in 1809. He had been a pupil of Benjamin Rush, and had among his pupils Robert Hare and Benjamin Silliman. He and his students made numerous contributions to theoretical, mineral, and biological chemistry.

C. A. BROWNE (*Jour. Chem. Ed.*, 1932, IX, 1744–1747) calls attention to an experiment, performed by Woodhouse, in which soot and pearl-ash were ignited in a covered crucible. After cooling, the mass was treated with water, and ammonia was detected among the products of the reaction.

KATHARINE S. LOVE AND P. H. EMMETT (*Jour. Chem. Ed.*, 1932, XI, 1748–1750) have repeated Woodhouse's experiment. They offer the explanation that atmospheric nitrogen is fixed with the formation of potassium cyanide. On addition of water, the temperature is sufficient to hydrolyze some of the cyanide with the liberation of ammonia. The work of Woodhouse " seems to be an early illustration of the fixation of nitrogen by the cyanide process."

J. S. H.

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